Alaska Park Science

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Alaska Regional Office
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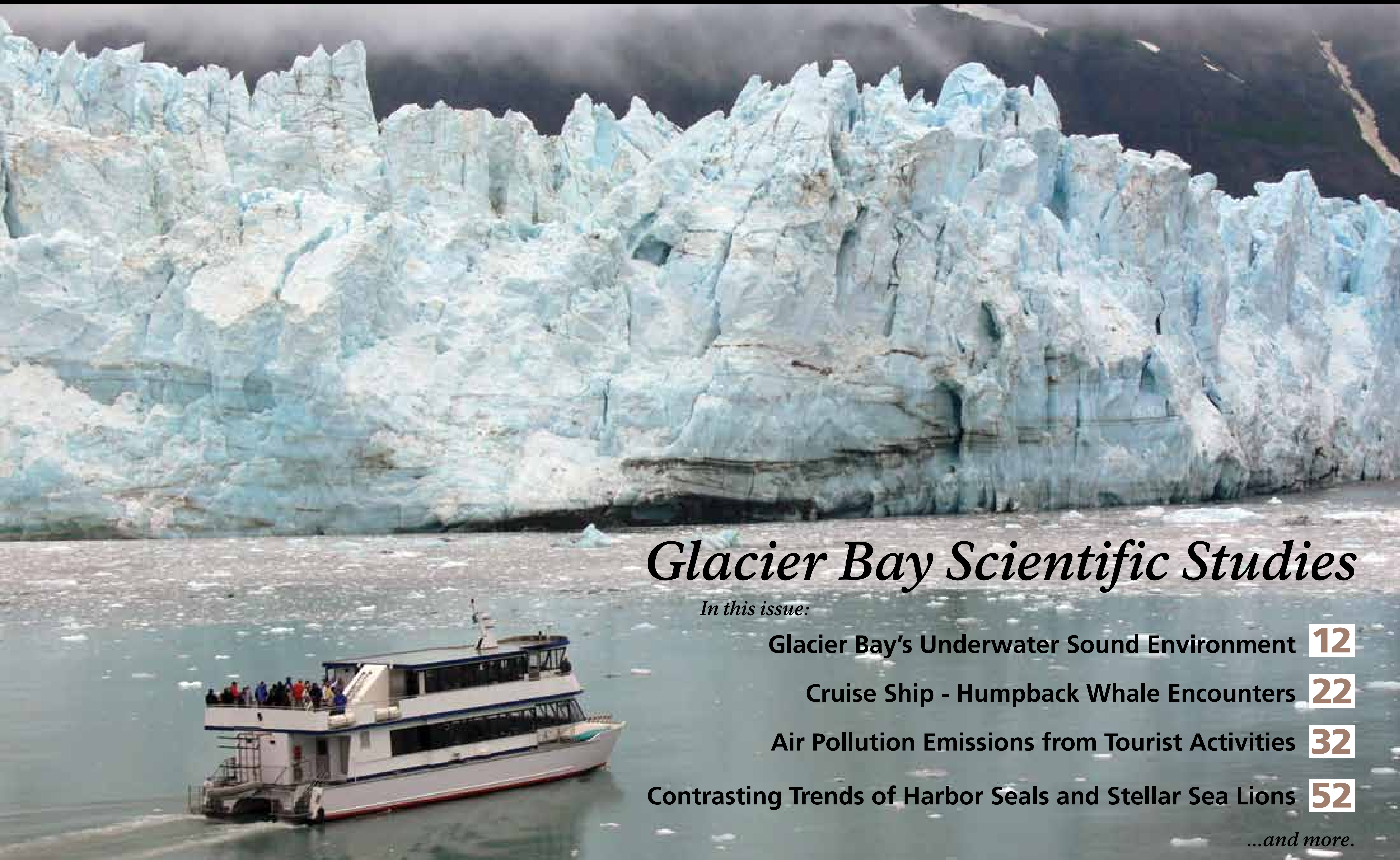

Glacier Bay Scientific Studies

In this issue:

Volume 9, Issue 2

Table of Contents

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Cruise ship seen from the stern.
NPS photograph

Cover photo: Day tour boat in Glacier Bay.
NPS photograph

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National parks are established *"…to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same… as will leave them unimpaired for future generations."* ORGANIC ACT 1916 (16 USC 1)

Introduction

By Cherry Payne, Scott Gende, and Tomie Lee

As the ship edges to the face of Margerie Glacier, 3,000 sets of eyes study the blue-white swath of ice. The ship, as long as three football fields and high as a small sky-scraper, is eerily silent as it slows to a stop. The glacier's groans and cracks and the call of the aptly named black legged kittiwakes are easy to hear. Seals, resting on ice floes, gaze at the steel behemoth before them. But below the decks, it is a different story: 1,300 crew operate a mini-factory to serve this city on the sea. Diesel generators pump out electricity, driving utility systems to make potable water, treat sewage, and provide climate control. In the water, azipods, looking like mini-submarines with mammoth propellers, allow the captain to spin the ship on its axis. In the summer months, this event happens daily. On most days, it happens twice daily.

Each year, over 400,000 people, the majority of park visitors, enter Glacier Bay National Park and Preserve on cruise ships. The experience is unparalleled, allowing multi-generational families from all over the world to witness the largest NPS marine park, whose waters nourish abundant wildlife and are found in a vast wilderness bounded by stunning scenery. In an unique program pioneered here, rangers board each ship to provide commentary over its public address system.

Figure 1. Cruise ship in Glacier Bay.

NPS photograph by Robert Winfree

Children earn Junior Ranger badges. Hundreds of passengers crowd the ship's theater to hear a ranger and often a Huna Tlingit cultural interpreter talk about this wild and remote piece of America. Surveys have found what many passengers communicate to the rangers: the day in Glacier Bay is the highlight of their Alaska cruise.

Tourist-laden ships began to visit Glacier Bay in 1883 but abruptly stopped in 1899 when earthquakes choked the bay with floating ice. The modern cruise ship era resumed with occasional visits in the 1950s. The number of ships increased substantially by the 1970s concurrent with a drop in endangered humpback whales feeding in the park. Soon, the park management was wrestling with issues related to ship quotas, vessel/marine mammal interactions, garbage disposal, stack emissions, and how cruise ships and other vessel traffic affect park visitors and park resources.

Every national park struggles with the two-fold NPS mandate of preservation and enjoyment. Overwhelmingly, most people who visit Glacier Bay do so via ship. But how many marine vessels are too many? Does their propeller noise interfere with wildlife foraging and communication? Do they displace whales or endangered sea lions found in the park? Do their stack emissions alter air quality? Do they disrupt resting animals or change feeding behaviors?

And how do large vessels, mainly cruise ships, affect the Huna Tlingit's perception of their homeland? What is the reaction by kayakers, other boaters, even people on the ships themselves when they see a cruise ship? For over 30 years, many have weighed in on these questions, resulting in nine pieces of legislation and one lawsuit that drives how vessels are managed in the park.

In 2003, the NPS established a process for vessel management in the *Vessel Quota and Operating Requirements Final Environmental Impact Statement* (VQOR FEIS). The Record of Decision (ROD) for that document directed the park to establish an independent Science Advisory Board, made up of ecologists, social scientists, engineers, biologists, to create a research framework to assess how cruise ships and other vessel traffic might affect the physical, biologic, cultural and sociological environment. The results of those studies would help inform the superintendent in applying the adaptive management approach called for in the VQOR FEIS: an annual determination of the level of marine traffic and the seasonal cruise ship quota based on park management objectives, applicable authorities, public comment and scientific information.

In 2004, following an open invitation to many state and federal agencies for nominations to serve on the Science Advisory Board, the first meeting occurred. A year later, the board submitted its first report to the park which highlighted a number of potential research efforts related to the impacts of cruise ships to park resources. In 2006, at the request of the park, the board submitted a prioritized research and monitoring framework. A number of those efforts were subsequently implemented or supported.

Science Advisory Board Members

Current	Past
Susan J. Alexander, Ph.D., Regional Economist, Alaska Region Secure Rural Schools Coordinator, Alaska Region, USDA Forest Service, Juneau AK.	**Gail Blundell, Ph.D.**, Harbor Seal Research Program, Division of Wildlife Conservation, Alaska Department of Fish and Game, Juneau, AK.
James L. Bodkin, Research Wildlife Biologist, USGS Alaska Science Center, Anchorage, AK.	**Heather Brandon**, Marine Policy Advisor, Alaska Department of Fish and Game, Juneau, AK.
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John K. Jansen, Wildlife Biologist, National Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA/NMFS, Seattle, WA.	
Blair Kipple, Naval Surface Warfare Center - Detachment Puget Sound, Silverdale, WA.	

Figure 2. Science Advisory Board members and affiliations

Timeline 1980 - 2010

1980
Concession permits established permitting entry by existing cruise ship operators; seasonal quota set at 89 vessels.

1984
Park General Management Plan limits cruise ship entries to no more than 2 per day; seasonal cruise ship entries increased to 102, and then, in 1987, to 107, based on a National Marine Fisheries Service Biological Opinion allowing a 20% increase.

1990
GLBA Cruise Ship Management Plan implemented with the objective of increasing opportunities for competitive allocation of entries (to provide park visitors with various choices); new round of competition for concession contracts were initiated.

1996
Finding of No Significant Impact (FONSI) for Vessel Management Plan Environmental Assessment allows 139 cruise ship entries, and up to 184 pending outcome of research on impacts; pollution minimization plans are required.

1998
A cruise line enters plea agreement and pays fine for unlawful discharge of oil; two years later the same company purchases two oil spill recovery barge/skimmers to be placed in the park.

2000
A cruise line funds measurement of the sound signature for one of its ships and begins submitting opacity/location records for each visit.

Figure 3. Timeline

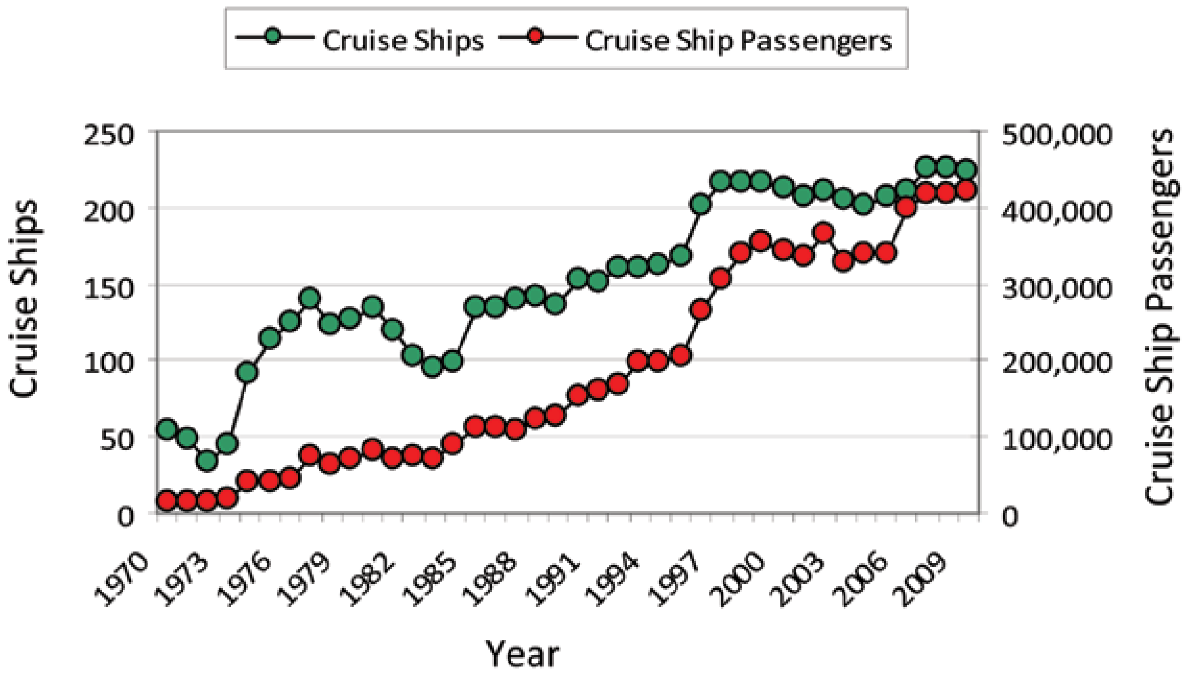


Figure 4. Glacier Bay Cruise Ship Numbers, 1970-2009

In December 2009, researchers, representing various disciplines, presented the results of their studies to one another, NPS managers and staff, and to the Science Advisory Board. The interdisciplinary approach and subsequent discussions will help inform the next round of management decisions for annual cruise ship entries to Glacier Bay, the appropriate level of smaller vessel traffic, and set the stage for the SAB's continuing work to recommend future research related to the question.

The studies, individually and across disciplines, will help the NPS to ensure that there are opportunities for high-quality experiences in the park while protecting the very resources that Americans cherish at Glacier Bay, now and into the future.

2001
Following a lawsuit filed in 1997, the NPS is found in violation of National Environmental Policy Act (NEPA) because the 1996 Vessel Management Plan was not an Environmental Impact Statement (EIS); court orders NPS to reduce seasonal entries to the pre-1996 level of 107.

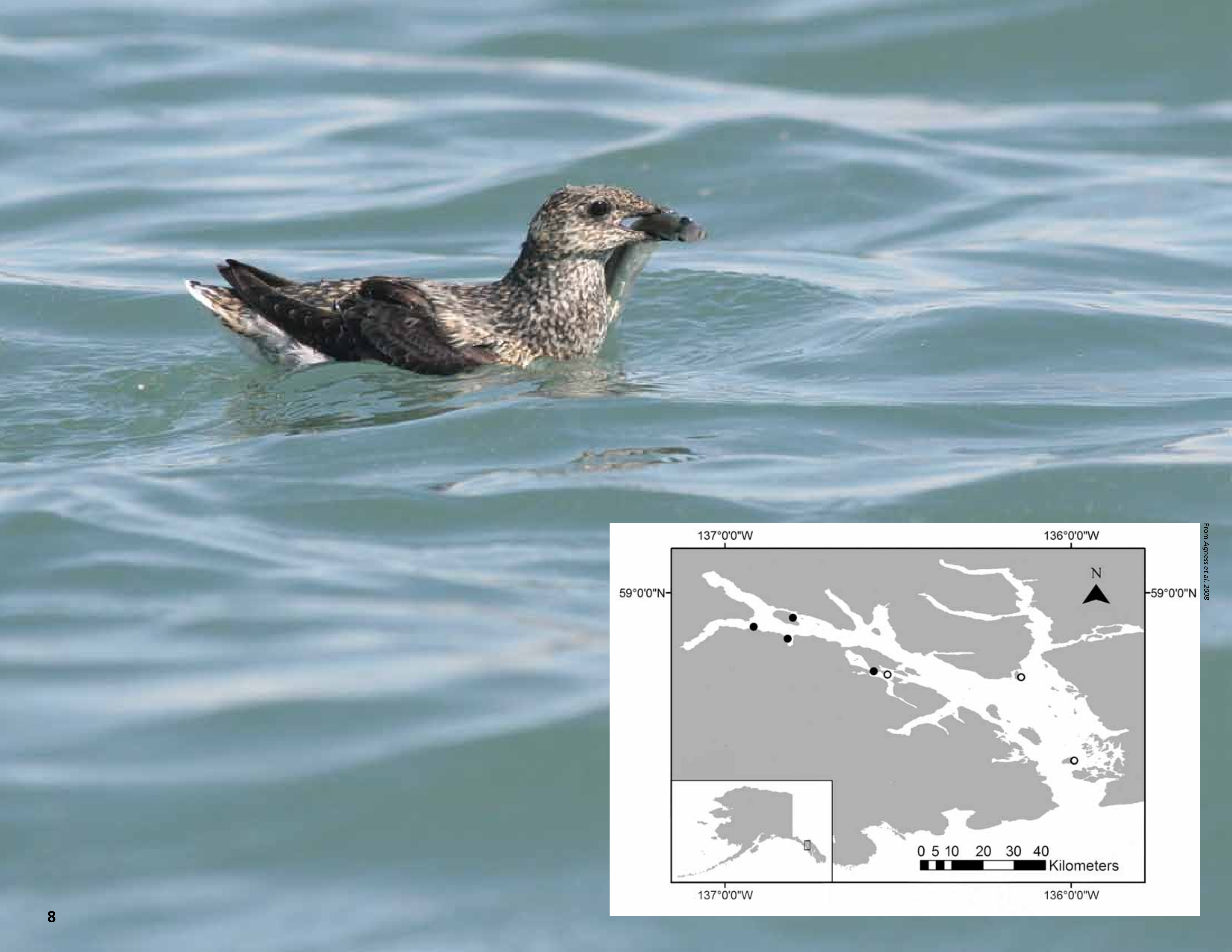
2002
The 2002 Interior Department Appropriations Act (PL 107-63) directs the NPS to complete a new vessel management plan EIS by January 1, 2004, and sets the cruise ship quota at 139.

2003
Record of Decision (ROD) issued for Vessel Quota and Operating Requirements EIS; sets the 92-day peak season (June-August) quota at 139, with potential to increase to a maximum of 184 (2 ships per day, every day during the peak season). Science Advisory Board formed to advise the superintendent regarding changes in cruise ship quotas.

2004
Male calf of humpback whale 1432 found dead near Strawberry Island in the park; necropsy revealed death was the result of blunt trauma, consistent with a vessel strike. Vessel was never identified.

2006
NPS publishes proposed vessel regulations which set limits for cruise ships during the shoulder season (May, September); superintendent increases quota for the 2007 peak season by 10%, to 153.

2010
New suite of cruise ship concession contracts takes effect; operators agree to continue new strategies to reduce air pollution, water pollution and underwater sound; one company offers to make enhancements to the interpretive/educational program and to develop and share with other companies a "whale strike avoidance program."



From Agness et al. 2008

Vessels Disturb Kittlitz's Murrelets in Glacier Bay National Park and Preserve

By Alison M. Agness

Abstract

The Kittlitz's murrelet is a candidate species for listing under the Endangered Species Act that has dramatically declined over the past three decades across its range. Glacier Bay National Park and Preserve supports a large portion of the world population of Kittlitz's murrelets during their summer breeding season. Although not a likely cause for the species decline, vessel disturbance contributes to the list of threats that currently face Kittlitz's murrelets. Research results indicate that vessels in Glacier Bay National Park and Preserve, including cruise ships, temporarily displace these birds and disrupt their behavior at energetic expense.

Introduction

The Kittlitz's murrelet is a rare seabird that spends most of its time at sea (*Day et al. 1999*). The species is a candidate for listing under the Endangered Species Act because of dramatic population declines documented over the past three decades across the species range including in Southeast Alaska (*Kuletz et al. 2003*). Possible causes for the species decline include oil pollution, fisheries bycatch, food limitations, and global climate change (*Day et al. 1999, Kuletz et al. 2003*).

Although not a likely cause for the species decline, vessel disturbance contributes to the threats that currently face Kittlitz's murrelets (*Agness et al. 2008, Agness et al. in prep*). Glacier Bay National Park and Preserve (GLBA) supports a large portion of the world population of Kittlitz's murrelets during their summer breeding season, where there is a high potential for vessel disturbance of these birds. Marine waters close to tidewater glaciers and the outflow of glacial streams are preferred foraging areas for Kittlitz's murrelets (*i.e., Day et al. 2003*), and these same glaciers are the primary draw for tourists and vessel activity in Glacier Bay.

Vessel traffic in Glacier Bay is regulated by the National Park Service to protect sensitive wildlife, and provide for visitor access and wilderness experience. Daily vessel quotas during the summer and vessel operating requirements, such as adherence to speed and area restrictions, are examples of the current vessel regulations in GLBA. The park's vessel management plan allows for future changes to daily quotas and operating requirements as necessary to protect the values and purpose of the park. The intent of our research was to learn about a little known species, the Kittliz's murrelet, investigate their interactions with vessels including cruise ships and by doing so, inform vessel management decisions in the park and elsewhere in Alaska.

Methods

A small field crew observed Kittlitz's murrelet density and behavior with standard techniques called area-scan and focal bird sampling to collect time-elapsed as well as instantaneous data on the birds at sea. Observations were made at seven sites where Kittlitz's murrelets occur in Glacier Bay, and sampling took place across daylight hours on regular intervals (*Figure 1*). Data were collected in the presence and absence of vessels. Sampling took note of opportunistic vessel events as well as a variety of environmental and habitat variables that may affect Kittlitz's murrelet behavior and presence, such as data on the tides and currents, weather, and time of day. When a vessel came through a study site, observers recorded the vessel size and speed, as well as behavioral response data for proximate Kittlitz's murrelets. Distance between the vessel and bird was also recorded at the point of behavioral response or at the closest point of approach, in the event that a bird did not respond.

The bird behaviors typical of Kittlitz's murrelets at sea that were recorded included loafing, diving, flying, fish-holding, and flying while holding a fish. Fish-holding behavior is indicative of breeding murrelets that are actively rearing a chick (*Carter and Sealy 1987*), and observers distinguished birds engaged in this behavior as breeding birds (*Figure 1*). It is not possible to tell the breeding status of murrelets that are not holding a fish, but for sake of distinction those not holding a fish were labeled non-breeders. An additional behavior, diving while holding a fish, which is not typical for Kittlitz's murrelets, was a recorded behavior in response to proximate vessels.

Statistical techniques were used to measure a variety of vessel effects on Kittlitz's murrelets and determine if the effects were immediate, short term (after 30 minutes), or long term (over a day). Modeling techniques were used to assess whether a bird's flight response from vessels could pose the risk of a fitness effect, or make it more difficult for the bird to successfully reproduce and survive. Potential fitness effects were evaluated as proportional increases in daily energy costs, from >

Figure 1. (Photo) A Kittlitz's murrelet engaged in fish-holding; this behavior indicates the murrelet is actively rearing a chick. (Map) Location of field sites in Glacier Bay, Alaska. The four sites marked with black circles were glacial, and the three sites with open circles were nonglacial.

NPS photograph

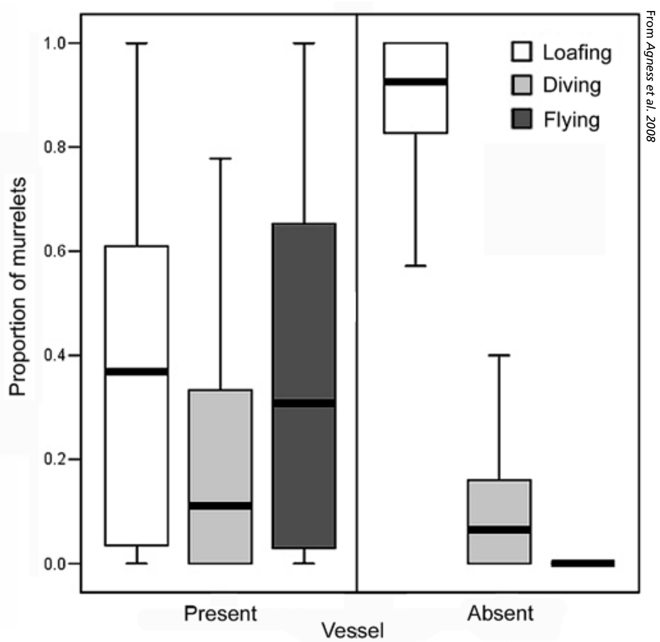


Figure 2. Kittlitz's murrelet behaviors summarized in the presence and absence of vessels. Black lines indicate median values, and significant behavioral change was detected for loafing (decrease) and flying (increase) in the presence of vessels.

0% to as high as a 50% increase, and also considered if the energy costs are chronic (i.e., occur on most days) or seldomly incurred (i.e., on very few days).

Results

Effects on Density

The density of Kittlitz's murrelets decreased in the short term, or 30 minutes after a vessel event, by an average of 40%. Over the course of a day, their density is more affected by environmental and biological variables than by vessels. Kittlitz's murrelet density was positively correlated with vessel traffic (higher density on days with higher rates of vessel traffic), for reasons that remain unclear. However, this result corroborates that short term decreases in density do not persist for very long.

Effects on Behavior

Vessels caused an immediate increase in flight response, from 0% of birds engaged in flight in the absence of vessels to 30% of birds engaged in flight in the immediate presence of vessels (*Figure 2*). Additionally, Kittlitz's murrelets dove three times more on days with vessel activity than on days without vessel activity, even though dive response overall did not significantly change during vessel events, with the exception of breeding birds described below.

Breeding birds were most likely to dive in response to vessels, which is not typical for fish-holders and was not observed in the absence of vessels. 95% of breeding birds dove in response to fast moving (> 10 miles/hr) vessels, regardless of vessel size or approach distance. Breeding birds also responded to vessels by flying away with their fish, which was most likely to happen in response to slow vessels (< 10 miles/hr) that approached at far distance (0.25 to > 0.5 miles away). Non-breeding birds were most likely to fly away from large vessels (cruise ships and tour boats), regardless of the vessel speed and approach distance.

Energy Costs

Average vessel conditions in the bay resulted in energy costs incurred to both breeding and non-breeding birds from their respective flight responses to vessels. Non-breeding birds incurred increased energy costs of < 10% additional cost on 86% of days and as much as >10% to < 30% additional cost on only 2% of days, whereas, breeding birds only incurred increased energy costs of <10% additional cost on 26% of days.

Discussion and Conclusions

This study demonstrated that Kittlitz's murrelets are temporarily displaced by vessels including cruise ships in Glacier Bay National Park and Preserve. Displacement following vessel events appears to be short-term, because bird density rebounded over the course of a day in the disturbed areas. Therefore, the birds' displacement by vessels does not result in a persistent loss of their preferred habitat in the park.

The study also identified vessel characteristics that are most likely to disturb Kittlitz's murrelets, and found that different vessel characteristics are attributed to response by breeding versus non-breeding birds. Breeding birds dove from vessels traveling at speeds less than 10 mi/hr, but even slow-moving vessels at far distance from these birds disturbed them and elicited a flight response. It appears that breeding birds are highly sensitive to vessel activity. Non-breeding birds, on the other hand, were most disturbed by large vessels (flew from cruise ships and tour boats), but were little affected by smaller vessels regardless of their speed or approach distance. Non-breeding birds appear less sensitive to the majority of vessel traffic in Glacier Bay.

Flight responses of Kittlitz's murrelets immediately following a vessel event were shown to incur energy costs; however, the risk of such costs leading to fitness effects is not equivalent for all birds. Chick-rearing is energetically costly, and it is more likely that any additional energy cost to a Kittlitz's murrelet during chick rearing could have a fitness effect. Whereas, non-breeding birds likely have more flexibility in their energy budgets. Therefore, although the study found that non-breeding birds incur increased energy costs on most days, is it very rare that the increase would be >10%, and likely that non-breeding birds can cope with additional costs <10% on a daily basis. It is still questionable whether they can cope with even small additional costs as a chronic condition, or almost every day.

Breeding birds, on the other hand, were found to incur additional energy costs from their flight responses about a quarter of the time (26% of days). Given the large energy expense these birds already incur to rear their chicks, it is likely that even the relatively low energy increases attributed to their flight responses from vessels, <10% increases, may cause fitness effects for these birds. On top of the costs incurred by flight, they were most likely to dive from vessels and the biological implications of diving for a fish-

NPS photograph

Figure 3. A cruise ship (left), kayak (middle) and tour boat (right) enjoy the West Arm of Glacier Bay, amidst prime Kittlitz's murrelet habitat.

holding bird may be significant (as shown in *Speckman et al. 2004*). If their diving leads to a dropped or eaten fish, the lost chick-meal could carry fitness effects to both the adult bird that expends additional energy to catch another fish as well as to its chick if a meal is not delivered.

Management Implications

Breeding Kittlitz's murrelets are highly sensitive to vessel activity, and susceptible to fitness effects from incurred energetic costs and potential loss of their held fish. The park could consider area restrictions to minimize vessel traffic during the season when Kittlitz's murrelets rear their chicks (~June 21-July 15 in Glacier Bay, *Agness 2006*), particularly in known Kittlitz's murrelet 'hot spots' in the bay. Speed restrictions in these areas (<10 mi/hr) may help minimize dive responses, but would not alleviate flight responses, and both types of disturbance carry potential fitness consequences for breeding birds.

Although non-breeding birds are less sensitive to vessel activity and less susceptible to fitness effects from incurred energetic costs, management action may still be warranted to reduce their daily energy costs incurred flying from large vessels, since this appears to occur chronically. For example, standard routes for cruise ships could be examined and altered as necessary to minimize their potential to encounter Kittlitz's murrelets, and standard routes for tour boats could be defined to the same end.

More research on Kittlitz's murrelets and their interactions with vessels would also help evaluate the utility of vessel management actions. For example, directed survey of Kittlitz's murrelets from cruise ships traveling along their standard routes would help evaluate the need for route alterations (i.e., are many or few birds encountered?). It would also be beneficial to conduct a tagged bird study, as the data that characterize duration of flight response currently represents minimum estimates (i.e., observations ceased when a bird flew out of direct line-of-sight from the land-based viewing stations), and evaluating time budgets from tagged birds would allow for more comprehensive energetic modeling than has been conducted to date.

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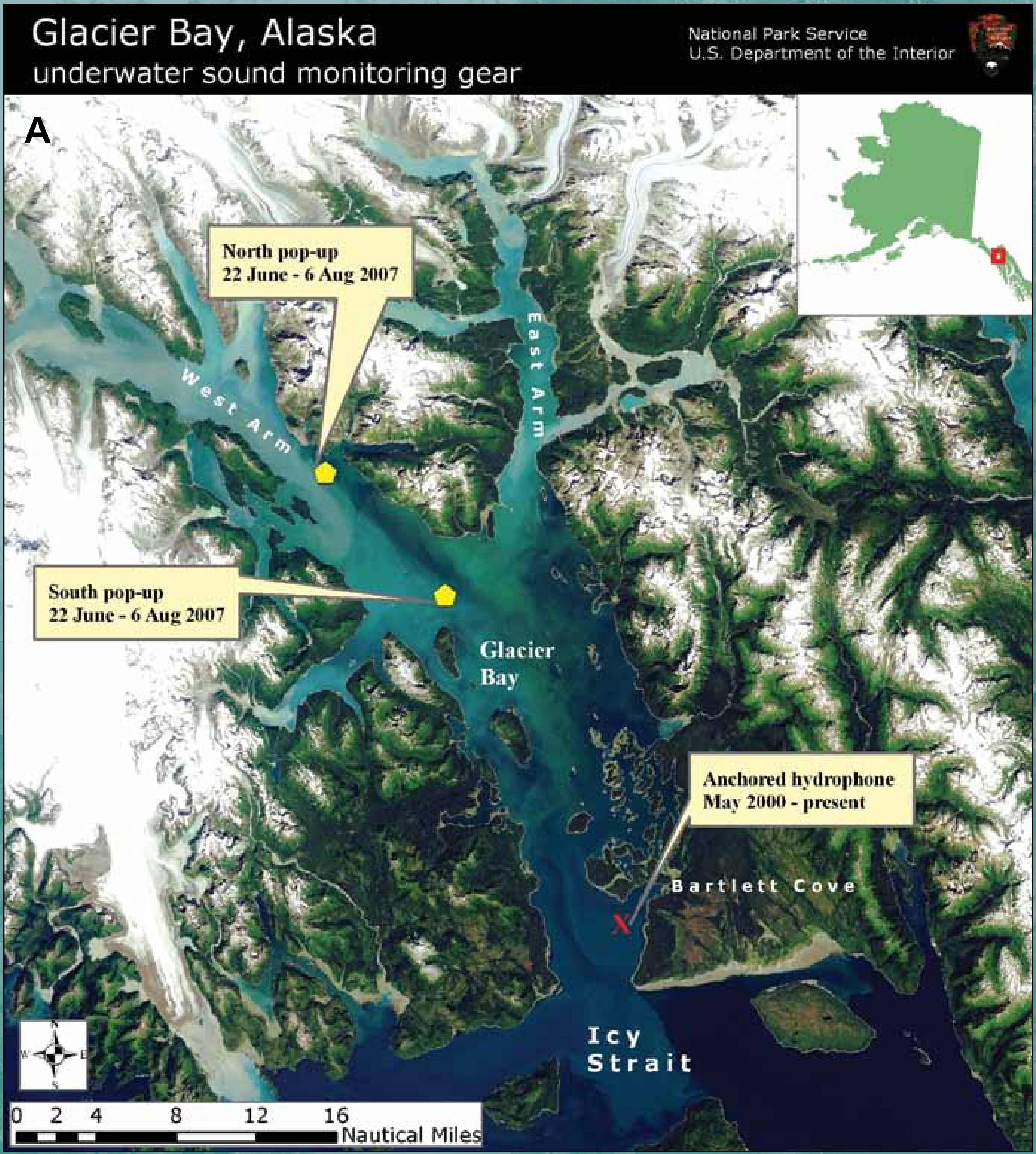


Figure 1. Underwater Sound Data Collection. (a) Since May 2000, a hydrophone anchored to the seafloor has allowed continuous monitoring of underwater sounds. (b) In 2007, two autonomous "pop-up" acoustic recorders were deployed for 45 days in Upper Glacier Bay to record continuous underwater sound. Park visitors can hear live sounds at kiosks at the Visitor Center.

Glacier Bay's Underwater Sound Environment: The Effects of Cruise Ship Noise on Humpback Whale Habitat

By Christine M. Gabriele, Christopher W. Clark, Adam S. Frankel, and Blair Kipple

Introduction

When you see a cruise ship floating majestically through the waters of Glacier Bay, it seems almost silent. But if you were a marine mammal underwater, you would hear a very different scene. Long before you could see the ship, you would hear the steady rumble of diesel-electric generators and the low-frequency drumming of its massive propellers pushing the ship forward. This cacophony would become louder until it dominated your acoustic sense, reducing your ability to hear other important sounds such as the school of fish you were hunting, or the killer whales that might be hunting you. You might not be able to tell exactly where the ship was located, to avoid getting struck by it. Calling to communicate with others would be useless with this level of noise. Eventually the dense cloud of ship noise would begin to ebb as the ship moved away, finally receding into the distance about an hour after you first started hearing it. Like the sun coming out from behind a cloud, the acoustic scene re-emerges and your acoustic habitat is yours again, but only until the noise from the next vessel appears on the horizon. Marine mammals that know and experience Glacier Bay through their ears undergo this kind of dynamic and reversible acoustic habitat loss many times every day.

Although the scientific details of whale auditory perception are not known, we do know that they are acoustically adept and rely on sound for basic life functions such as feeding, finding mates, detecting predators and maintaining social bonds. Vessel noise can thus interfere with the daily activities of whales; however, almost all park visitors who come to see the whales in Glacier Bay National Park (GLBA) travel on cruise ships and other motorized vessels. To address this collision of the senses, GLBA is collaborating with acoustic experts to understand underwater noise and to look for ways to mitigate noise effects on the endangered humpback whales that spend their summers in park waters. GLBA is mandated to manage the number and behavior of cruise ships and other vessels in such a way as to minimize their effects on park resources. While quotas for private, charter and tour vessels have been set at levels defined in the Code of Federal Regulations enacted in 2006 (36 CFR 13, subpart N), GLBA is faced with defining cruise ship quotas on an annual basis, based on a variety of scientific and other information sources.

Here we describe three related avenues of inquiry that seek to quantify vessel-generated underwater sound and predict its effects on the acoustic habitat of humpback whales in GLBA. Large vessel traffic contributes substantial amounts of underwater noise into marine environments worldwide, but few other quantitative studies in marine protected areas have been attempted (*Hatch et al. 2008*). It is important to note that in addition to the numerous potential impacts of man-made noise on wildlife (*Barber et al. 2009*), the natural soundscape is gaining prominence as a park resource with its own intrinsic value (*Fristrup et al. 2009*). Underwater and airborne soundscapes are among GLBA's 'Vital Signs' for the Inventory and Monitoring Program (see http://science.nature.nps.gov/im/units/sean/o_About.aspx).

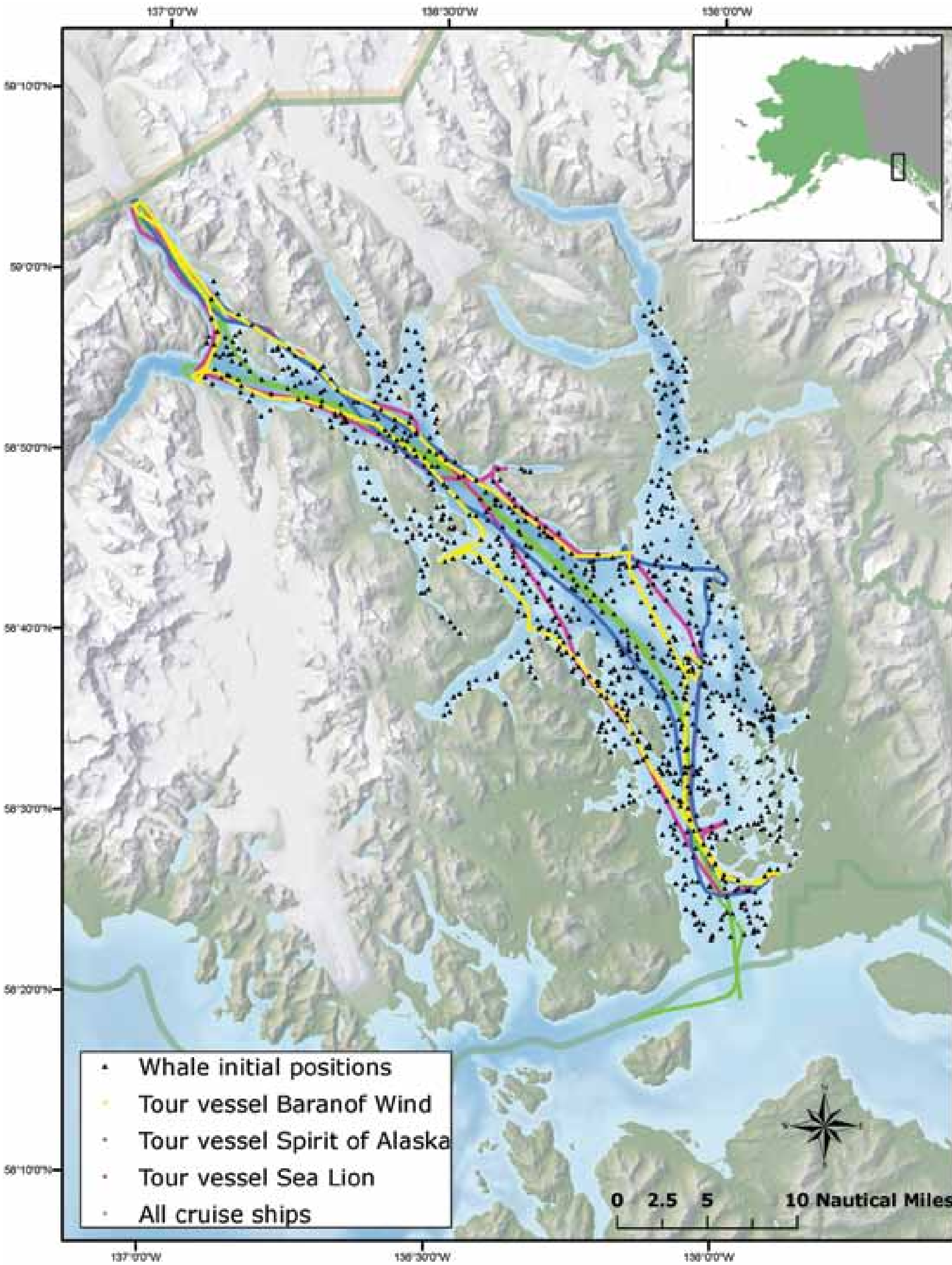
Methods

Calibrated Measurements of Individual Vessels

In 1999, the park began its acoustic monitoring program in collaboration with the U.S. Navy by making calibrated measurements of cruise ship underwater sound at the Navy's Southeast Alaska Acoustic Measurement Facility in Ketchikan, Alaska. So far, ten ships have been measured at different travel speeds, with voluntary cooperation of cruise lines. These calibrated measurements, called "sound signatures" were among the world's first quantitative descriptions of cruise ship sounds, giving us our first indication of the effect of ship speed on sound output (*Kipple 2002*). Between 2000 and 2009, we measured the sound signatures of 32 small vessels ranging from a 14 ft skiff to a 250 ft tour boat. Little previous sound signature data existed for small vessels. These sound signatures are an important data source for modeling noise exposures, described below, to predict the effects of vessel management options.

Collecting Ambient Noise Recordings

Since May 2000, GLBA has recorded and analyzed sounds near the entrance to Glacier Bay (*Figure 1*). We monitored underwater sound using a calibrated hydrophone anchored at 95 ft depth, connected by a submerged cable to a custom-built computer at park headquarters (*Figure 1a*). The computer displays a continuous real-time sound spectrogram and collects an automated 30-second sample every hour and records it in a database. Since 2005, the system has also collected continuous sound recordings. In 2007, GLBA collaborated with the Bioacoustics Research Program at Cornell University to place two marine autonomous acoustic recorders (pop-ups) in upper Glacier Bay to record 45 days of continuous acoustic data (*Figure 1b*). Both types of recordings enabled us to document and summarize the characteristics and prevalence of natural and man-made sounds in Glacier Bay.



Modeling to Predict the Effects of Vessel Quotas and Speeds

We used the Acoustic Integration Model© (AIM), developed by Marine Acoustics Incorporated, to simulate whale and vessel movement through time and three dimensions of space (i.e., ocean volume) under 11 different scenarios by varying the number, speeds and arrival times of cruise ships and tour vessels as they moved among 1,000 simulated whales scattered throughout Glacier Bay (*Frankel and Gabriele, submitted*). Existing data on Glacier Bay bathymetry (*Hooge et al. 2004*), sound propagation (*Malme et al. 1982*) and humpback whale distribution (*Neilson and Gabriele 2009*) were incorporated into the model. The modeling effort focused specifically on large vessels to provide information relevant to decisions on future changes in cruise ship numbers and operations, though smaller vessels are known to contribute significantly to underwater noise levels in the park (*Kipple 2003, Kipple and Gabriele 2003b*).

Cruise ship acoustic characteristics at 10 and 20 knot speeds were derived from calibrated measurements of four ships (*Kipple 2002, 2004a, 2004b*). Acoustic exposure, defined as the estimated quantity of sound that each simulated 'whale' received, was quantified with two metrics: maximum sound pressure level (MSPL) and the daily integrated sound exposure level (SEL). Using these and other raw materials, AIM computed the received sound level for each 'whale' every 30 seconds and compiled them into an acoustic exposure time history for each 'whale'.

Key Results - Ambient Noise

- The proportion of underwater sound samples that contained motor vessel noise increased from 51% in 2000-2002 to 59% in 2007-2008 overall for May through September (*Figure 3*). The 5% increase in cruise ships over time (mean 210 vs. 220 ships annually) likely explains some of this noise increase, but the approximately 100% increase in private vessel entries was almost certainly an even more important factor.

Figure 2. Ship Track and Whale Distribution in Acoustic Integration Model (AIM). One or two simulated cruise ships and three tour vessels of known underwater sound characteristics travelled through a Glacier Bay filled with 1,000 hypothetical whales. All runs used the same vessel tracks but ship speed (13 vs. 20 knots), numbers and arrival times varied, to estimate the effects of potential management decisions on whale noise exposure.

- Individual vessels are almost always quieter at slower speeds, and this likely explains why the underwater noise environment in Glacier Bay was substantially quieter when vessels were required to travel at 13 knots rather than at 20 knots (*Kipple and Gabriele 2003b*).
- Cruise ships are audible (> 3 decibels above natural background noise levels) for 40-74 minutes each time they enter or exit Glacier Bay as measured at the anchored hydrophone in the Lower Bay (*Figure 5*) (*Clark 2007*).
- Humpback whale song, a mating-related male display (with prolonged bouts in September through November), and male harbor seal territorial roaring (present in almost every hourly sample in June and July) were the most pervasive biological sounds detected. Simple humpback whale "whup" calls were the most common whale vocalization heard, probably functioning as contact calls among all age-sex classes of whales.

Key Results - AIM Model

- Cruise ship speed appeared to be the dominant factor in determining the noise levels to which whales were exposed. Median daily and maximal noise exposures in AIM runs with two slow cruise ships were lower than those with a single fast cruise ship (*Figure 4*).
- Although the slower, quieter 13-knot ships exposed whales to noise for a longer period of time, the faster, louder 20 knot ships produced significantly ($F = 1923.16$, $df = 3$, $p < 0.001$) greater maximal and daily noise exposures. Although a 13 knot ship takes 1.5 times longer to pass by than a 20 knot ship, a listener would need to hear a slow ship approximately 7.5 times longer than a fast ship to experience the same noise exposure, (*Frankel and Gabriele, submitted*).
- Smaller tour vessels contributed substantially to underwater noise on days that are relatively quiet (i.e., days with one slow cruise ship), but on relatively noisy days (i.e., days with two fast cruise ships) tour vessel noise resulted in little additional noise exposure for whales.

Next Steps and Reccomendations

Prior to this study, the natural underwater sound environment, the role of vessels, and the potential effects of noise on the acoustic environment of Glacier Bay were unknown. Through ambient noise monitoring, we demonstrated that increases in vessel traffic of all kinds resulted in a decrease in the availability of natural sound conditions at the mouth of Glacier Bay (*Figure 3*). We also documented that seals and whales frequently use the natural soundscape for their vocalizations (*Kipple and Gabriele 2003b*). We have also made the first steps toward predicting the effects of specific cruise ship management actions on the underwater acoustic habitat for different marine species that depend on this habitat seasonally or year-round. These findings provide a cornerstone for decisions about the management of cruise ships and other vessel traffic in the park, but the most challenging tasks still lie ahead.

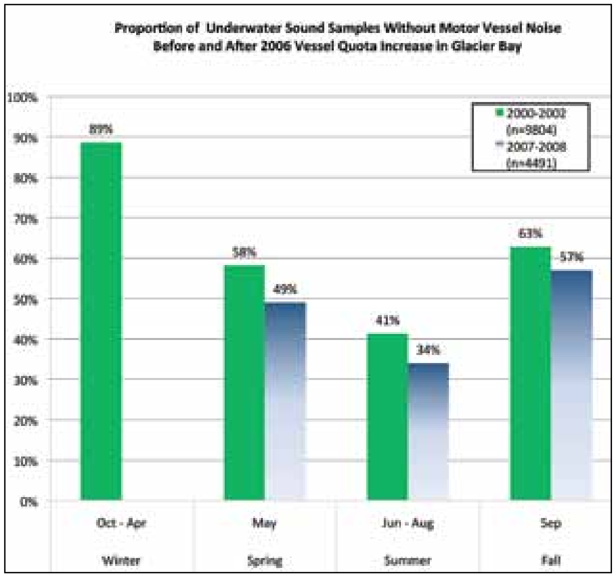


Figure 3. Hourly 30-sec samples of underwater sound were examined for the presence or absence of motor vessel noise, before and after the 2006 vessel quota increase. The proportion of samples containing vessel noise increased from 51% to 59% for May - September. Winter samples for 2007-2008 were not examined, to focus analysis effort on the main visitor season.

It is extremely difficult to assign a particular decibel level or proportion of time when the underwater sound environment is dominated by vessel noise (*Figure 3*) as the "acceptable" level of man-made noise to meet the NPS mandate to preserve natural habitats "unimpaired". However, the difficult and ultimately subjective process of defining the desired future condition of Glacier Bay's underwater acoustic environment is precisely what awaits park managers.

One step toward that goal is to build a long-term, understanding of Glacier Bay bioacoustic habitat for key marine mammal species such as humpback whales, harbor seals and killer whales. One aspect of this endeavor will be to develop a communication-masking metric to quantify the percentage of lost acoustic habitat for each species (*Figure 6*) (*Clark et al. 2009*). Data collection to describe acoustic conditions throughout Glacier Bay, a better understanding of marine mammal hearing, and continuing to obtain sound signatures from the ever-changing cruise ship fleet will provide an essential basis for such efforts.

In the meantime, the results from this study provide park managers with some guidance toward ongoing cruise ship management decisions. The AIM modeling indicates that slower vessel speed was one of the most effective ways to reduce cruise ship underwater sound impacts. The best available information also indicates that reducing vessel speed reduces the probability of whale mortalities resulting from collisions between vessels and whales (*Laist et al. 2001, Vanderlaan and Taggart 2007*), and studies are underway to empirically test this idea in and around Glacier Bay (*Harris et al. this volume, Gende et al. this volume*).

As terrestrial, vision-centric humans, it not easy for us to fully grasp the importance of the underwater sound environment as a key marine habitat characteristic, even if we conceptually understand that marine animals depend on what they hear to make their daily living. Fortunately, Glacier Bay is relatively quiet in comparison to industrialized parts of the ocean (*Hatch et al. 2008, Clark et al. 2009*), where there is concern that chronic noise influences individual life histories and may exert population level effects. Even in chronically noisy ocean habitats, direct biological impacts are not readily apparent and not often predictable. However, even in the absence of documented biological effects, natural sound environments have intrinsic value that warrant protection on an equal footing with other natural resources in national parks. While industrialized underwater habitats will be very difficult to restore, national parks have a unique and profoundly important opportunity to preserve natural underwater sound environments and prevent the loss of acoustic habitat. If a marine protected area "should be a place that provides exceptional ecological protection for marine species" (*Haren 2007*) then acoustic habitat protection is an essential component of ecologically meaningful protection. Moreover, marine protected areas like Glacier Bay National Park and Preserve have a special role as natural laboratories that can foster an improved understanding of anthropogenic noise and creative approaches to reducing its effects on marine life.

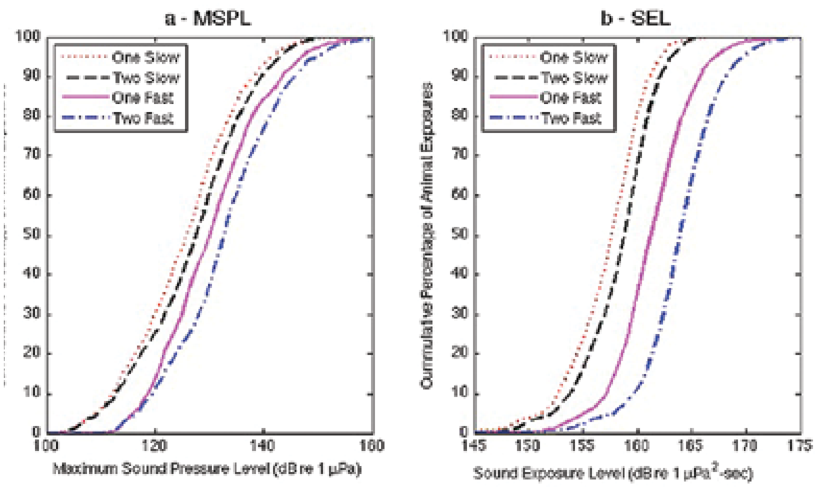


Figure 4. Cumulative probability functions for AIM simulations (a) MSPL = the single loudest sound level to which each hypothetical whale was exposed (b) SEL = the sum of all sound energy received by each hypothetical whale over the course of a day. Cruise ship speed was the dominant factor - runs with two slow ships were quieter than ones with one fast ship. Decibels use a logarithmic scale so differences in dB indicate large differences in magnitude. Doubling a sound's amplitude produces a 6 dB SPL increase.

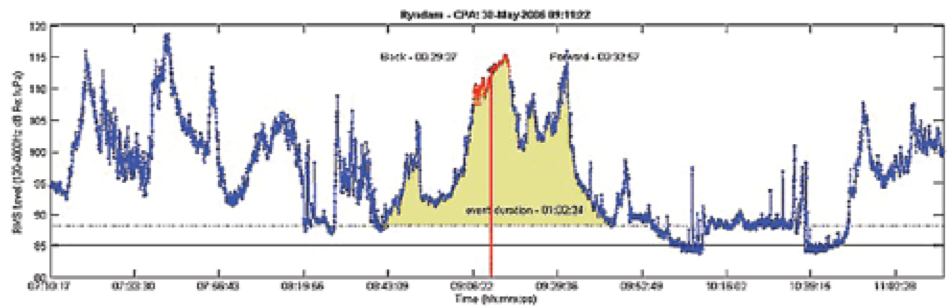


Figure 5. Cruise Ship Event Durations in Lower Glacier Bay. Events were defined as times when ship noise continuously exceeded estimated background noise by 3dB. Durations ranged from 41 minutes to 1 hour 14 minutes (n = 10).

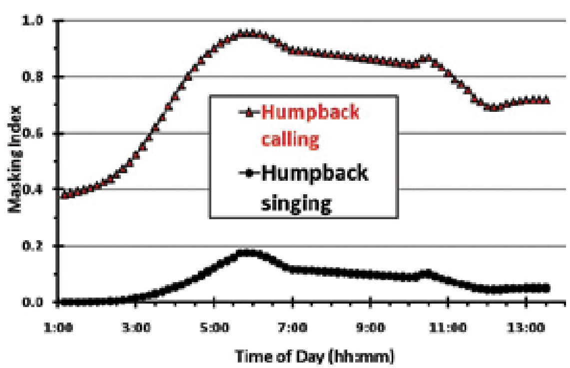


Figure 6. Effect of Vessel Noise Masking on Humpback Whale Vocalizations. Humpback whales are suspected to communicate at distances of at least 6.2 miles (10 km) in natural sound environments. Masking occurs when noise impedes a listener's ability to understand, recognize or detect sounds of interest. The Masking Index shows the percentage change in a whale's acoustic habitat caused by interfering noise. A humpback whale making a simple "whup" call loses more of its acoustic habitat (40-95%) than a singing humpback (< 20%) in the same noise conditions because song is louder, more repetitive and spans a wider frequency range, making it more detectable by other whales. Visit http://www.nps.gov/glba/naturescience/soundclips.htm to hear examples of whale and vessel sounds.

Acknowledgements

This study would not have been possible without the assistance of many Glacier Bay National Park and Preserve staff, data analysts at the Navy's Naval Surface Warfare Center, and Russ Charif and Dimitri Ponirakis of the Bioacoustics Research Program at Cornell Laboratory of Ornithology's Bioacoustics Research Program. We also thank Holland America, Princess, Norwegian, Crystal and World Explorer Cruise Lines for their participation in the sound signature measurements. Initial funding for ambient noise monitoring was provided by the National Park Service Fee Demonstration Program.

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Using Observers to Record Encounters Between Cruise Ships and Humpback Whales

By Scott M. Gende, Karin Harris, Julie Nielsen, and A. Noble Hendrix

In the early morning of July 12, 2001, the cruise ship Dawn Princess entered Glacier Bay National Park and Preserve, as it had on a number of occasions that year. After spending the day in Glacier Bay, the ship, measuring over 850 feet long and carrying nearly 3000 passengers and crew, headed back toward the mouth of the park, in clear weather and calm seas. Just after 2:30 pm as the ship neared Bartlett Cove, the captain reduced the ship's speed to allow NPS interpretive rangers to disembark to the ranger boat that had come along side. After the transfer, the ship increased its speed and began its transit outside the park to Icy Strait.

According to reports, as the ship increased speed several humpback whales were sighted approximately 700 yards (640 m) off the left side of the ship headed in a direction of the ship's path. Although the ship was accelerating, it did not alter its course and neither did the whales. At last sighting, the whales were so close to the ship that they could no longer be seen under the ship's prow. Thereafter, some passengers reported hearing a "resounding thud". Other passengers said they heard or felt nothing at all. Neither of the whales were seen re-surfacing on the other side of the ship, the incident went un-reported to the NPS, and the ship continued to its next port of call.

Four days later, a dead humpback whale was discovered bloated and floating near the area where the encounter occurred. A necropsy performed several days later found that the whale had a fractured skull and vertebrae, and likely died as a result of the massive blunt trauma it sustained to the right side of its head. It was also discovered that the whale was pregnant at the time of death.

Unintentional ship-whale encounters have increased over the past few decades as whale populations rebound from the large-scale commercial whaling in the 1950s and 1960s, and as the number and size of ships plying the world's waters have increased. In Glacier Bay, encounters between cruise ships and humpback whales have also likely increased for the same reasons. In 1970, cruise ships entered the park on 55 different occasions, but by 2009 that number had risen to 224, an increase of over 300%. Likewise, monitoring efforts in 1985 recorded 41 individual humpback whales using the waters in Glacier Bay and Icy Strait. By 2009, that number had surpassed 150, an increase of over 270%.

Encounters between cruise ships and humpback whales represent a perplexing issue for park management, reflecting trade-offs between resource protection and visitor experience. Although no formal surveys have been conducted, we have interacted with hundreds of cruise passengers over the past five years and found two recurring themes: (1) sighting a humpback whale represents one of the most thrilling experiences by cruise ship passengers, and (2) the closer the encounter, the more thrilling the experience. For example, one of the most common questions we are asked by passengers is when and where they are most likely to see whales. It's also hard not to notice the excitement of the wide-eyed passengers yelling to no one in particular that the whales were so close they could "see down the blowhole!" For many of these passengers, seeing whales may be a once-in-a-lifetime event, which undoubtedly invokes a keener appreciation for conservation and natural history, clearly consistent with the NPS mandate.

Nevertheless the same encounters coveted by passengers could have adverse impacts on individual whales, and ultimately affect the population using the park and adjacent waters. For example, the underwater noise produced by the propulsion systems of cruise ships may be sufficiently loud to degrade the whale's acoustic habitat (*Gabriele et al. this issue*) and mask vital communication for whales. As a general rule, the closer that ships encounter whales the louder the noise exposure, and thus the higher likelihood of impacting communication.

Figure 1. An endangered humpback whale surfaces in Glacier Bay National Park and Preserve with a cruise ship in the background. Interactions between ships and whales are frequent in Glacier Bay and adjacent waters. Park management and other agencies must consider how daily and seasonal levels of cruise ship traffic to this area might impact the population of whales.

NPS photograph

If encounters between whales and ships are too close, lethal collisions may occur thereby directly impacting the number of whales using Glacier Bay, both the year it occurred and in the future (*Gende and Hendrix this issue*).

Recognizing this potential impact, the Glacier Bay Science Advisory Board recommended as one of its top research priorities that the NPS place observers aboard the ships to record how often and how close cruise ships encounter humpback whales and other marine life. Beginning in July 2006, observers began spending the day aboard the ships while they were in the park. Observers, transferred out to the ships with the NPS interpretive rangers, position themselves on the bow with rangefinder binoculars and handheld GPS units, and record encounters beginning and ending near Bartlett Cove (*Figure 2*). After 2007, however, it was apparent that many of the encounters between ships and whales were occurring before or after the observers embarked/disembarked, particularly at the mouth of Glacier Bay and in adjacent Icy Strait. Thus, beginning in 2008, with funding provided by the National Fish and Wildlife Foundation and the Pacific Life Foundation, and in cooperation with the University of Washington and University of Alaska Southeast, observers began boarding ships in Skagway and Juneau to record encounters in Icy Strait and at the entrance of the park. Observers would then disembark at the ship's next port of call (Ketchikan or Sitka), fly back to Juneau and repeat.

By the end of the 2009 cruise ship season, observers had been aboard 23 different cruise ships constituting 380 different entries into the park or 49% of all entries since the project's inception. During these cruises, observers have logged over 2,700 hours and recorded over 1,600 unique encounters between whales and cruise ships.

Although analyses of these data are ongoing, simple descriptive statistics have revealed some management-relevant results. Foremost, encounters between cruise ships and whales are frequent, with many encounters occurring close to the ships. After truncating the maximum encounter distance to 3,281 ft (1 km), about 20% of the ship-whale encounters occurred within 985 ft (300 m) of the bow. Although only about 3% of these encounters were less than 328 ft (100 m), by any measure these encounters represent 'near misses'. For example, an adult whale swimming perpendicular toward the ship's path at

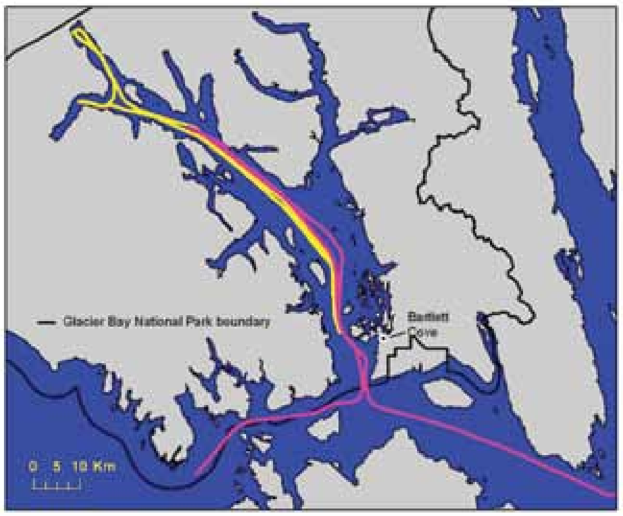


Figure 2. Typical routes of cruise ships accessing Glacier Bay National Park and Preserve. The yellow tracks indicate the typical area of coverage when observers boarded ships via the NPS ranger boat based out of Bartlett Cove. The pink tracks indicate the typical area of coverage when observers embarked cruise ships in Skagway or Juneau, and disembarked in Sitka or Ketchikan.

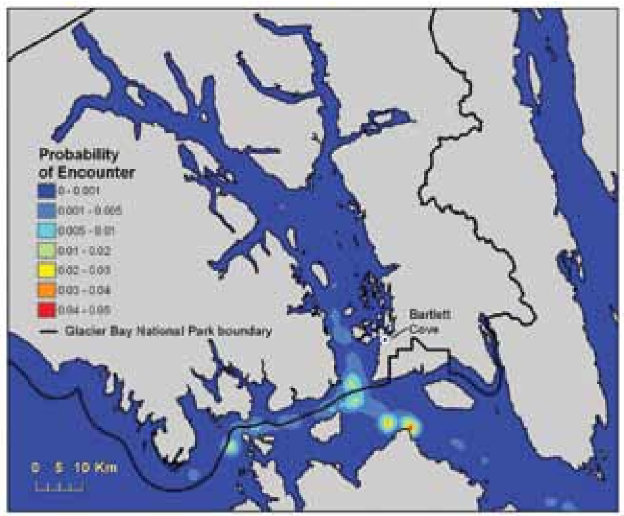


Figure 3. The kriged probability of a humpback whale encountering the bulbous bow of a cruise ship within 3,280 ft (1,000 m), standardized by effort 2006-2009. These spatial data indicate that the 'hotspots' of encounters are in the lower areas of the park and adjacent Icy Strait. The red areas represent a 5-10 fold increase in the probability of encounter compared to the light blue areas.

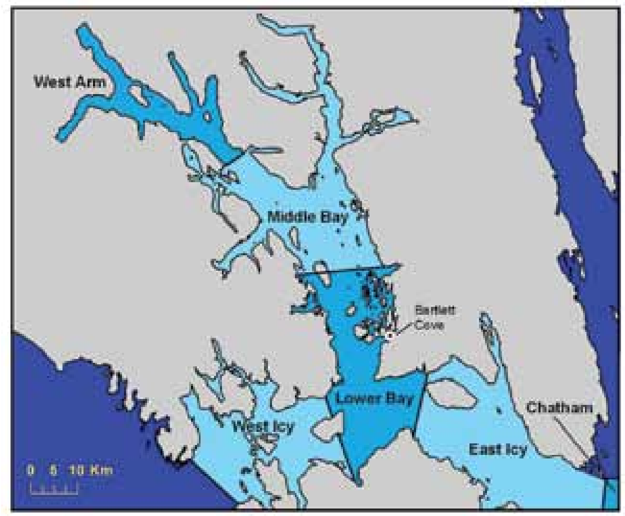


Figure 4. The sub-regions of the entire study area. These sub-regions were initially delineated based upon long-term average differences in oceanographic conditions and whale densities.

a typical speed of 7.2 ft/sec (2.2 m/sec), from 165 ft (50 m) away has about 6 seconds to avoid a collision with a ship moving at a speed of 16 knots (about 26 ft/sec or 8 m/sec).

Furthermore, owing to the distribution of whales in the park (as ships generally follow the same route) the probability of a ship-whale encounter is dramatically different in different areas of Glacier Bay and adjacent waters (*Figure 3*). Subdividing the study area in space (*Figure 4*) and in time demonstrates that the probability of an encounter differs dramatically among sub-regions and among months. For example, summing up the total number of encounters between whales and ships less than 1/4 mile (402 m) in each sub-region and dividing by the total number of ship entries into that sub-region reveals that the probability of an encounter is always high in the Lower Bay sub-region, particularly during the June-August peak season compared to the Middle Bay and West Arm sub-regions (*Figure 8*). However, high rates of encounters, undoubtedly with the same group of whales using Glacier Bay, can also occur in Icy Strait. These data suggest that park regulations for managing ships during peak versus 'shoulder' seasons, and instigating seasonal speed restrictions in the lower section of Glacier Bay are solid management actions, but should be considered in Icy Strait by the state of Alaska.

Ultimately, encounters between cruise ships and humpback whales are inevitable as long as both are plying the relatively confined areas of Icy Strait and Glacier Bay. What remains to be determined is whether these encounters adversely affect the whales using Glacier Bay and Icy Strait (*Gende and Hendrix this issue*), and the chance of another lethal collision between a whale and ship. Whether the level of cruise ships and associated visitation justifies the impacts to humpback whales will continue to be a significant management question. For now, the passengers will continue to enjoy experiencing these encounters, we will continue to to record and analyze their impacts, and managers will need to ultimately weigh both the visitor levels and rates of encounters to make decisions regarding quotas of cruise ships.

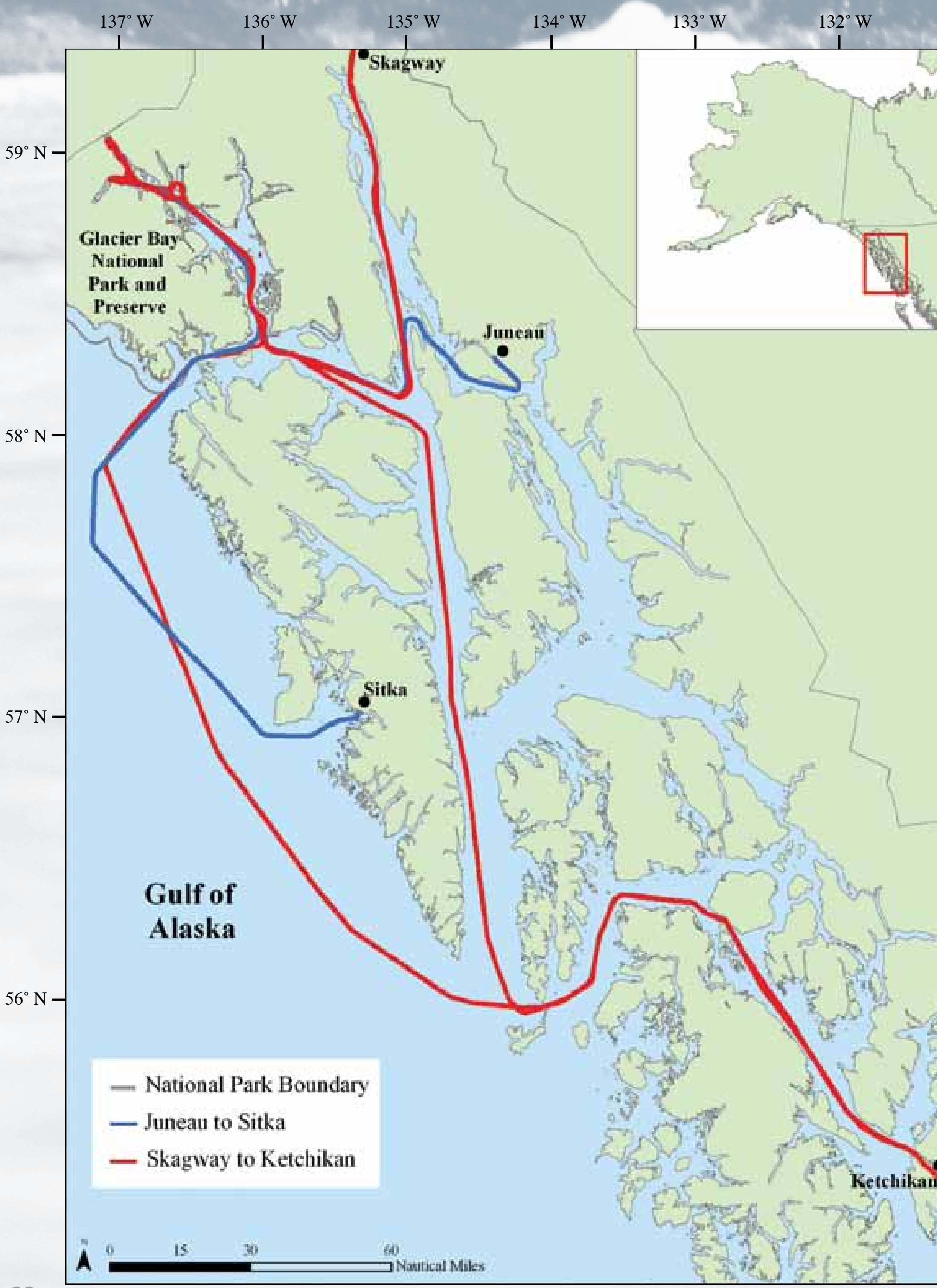
NPS photograph

Figure 5. A humpback whale discovered near the entrance of Glacier Bay National Park and Preserve in 2001. Necroscopy reports indicated that it died of blunt trauma consistent with a collision with a large vessel.

NPS photograph

Figure 6. An observer stationed near the bow of a cruise ship with laser rangefinder binoculars. Observers have been placed aboard almost half of all ships that have entered the park since 2006, and have recorded over 1,600 encounters between ships and whales.

Given that whales spend much of their time underwater out of view, a common question is whether or not it is illegal for cruise ships to hit a whale. When we are asked that question, our answer is some form of "well, it depends". Paraphrasing from the Code of Federal Regulations, 50 CFR § 224.103 (3)(b), it is unlawful to approach a humpback whale within 100 yards (91.4 m) or disrupt the normal behavior or prior activity, unless the maneuverability of the ship is restricted. Otherwise, ships must operate at a 'slow, safe speed when near a humpback whale'. So what constitutes a safe speed? Ships should operate in such a manner that allows them to take proper and effective action to avoid a collision, which will vary with such factors as visibility, maneuverability, and sea surface conditions, among others. So what happens when the ship has no visibility of the object with which it may collide? For example, a whale that may spend 10-20 minutes underwater prior to re-surfacing near the ship?


137° W
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Skagway
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Juneau to Sitka
Skagway to Ketchikan
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15
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Cruise Ship – Humpback Whale Encounters In and Around Glacier Bay National Park and Preserve, Alaska

By Karin Harris and Scott Gende

Abstract

Understanding how the presence of cruise ships may affect humpback whales is a research priority for managers of Glacier Bay National Park and Preserve. An observer boarded cruise ships in 2008 and 2009 to document how often and how close ships encountered whales as ships transited the park and adjacent waters. Results from this study can inform managers of the frequency and severity of encounters and assist them in evaluating policy options that seek to balance visitor experience with protection of valuable biological resources.

Introduction

Information on how often and how close cruise ships encounter humpback whales can help managers decide how many cruise ships should be allowed to enter the park each season. This type of information can also be used to develop policies designed to minimize potential impacts to natural resources like humpback whales while also providing opportunities for visitors to enjoy these resources. Currently Glacier Bay National Park and Preserve (GLBA) limits the number of cruise ships to no more than 2 ships per day and no more than 153 during the peak season, which is June to August (*36 C.F.R. pt. 13, 2006*). The park also enforces additional protection measures such as speed restrictions in portions of the park, where the probability of whale occurrence is high. Two lethal injuries to whales from ship strikes have been confirmed in the park, one in 2001 when a large cruise ship collided with and killed an adult humpback whale (*Doherty and Gabriele 2001*) and another in 2004 when a humpback whale calf washed ashore in park waters with injuries attributed to a collision with a vessel (*Doherty and Gabriele 2004*). In Southeast Alaska, there has been an increase in reporting of ship and whale collisions (*Gabriele et al. 2007*), yet few data exist that documents the frequency and severity of encounters. Expanding on a shipboard observer project initiated within GLBA in 2006, a graduate student from the University of Washington was given a unique opportunity in 2008 and 2009 to travel aboard cruise ships and document the frequency (how often) and severity (how close) of encounters between cruise ships and whales both inside and outside the park. The study was designed to identify locations where ships encountered whales most frequently in Glacier Bay and adjacent waters.

Figure 1. (Map) Cruise ships boarded from Juneau followed the same route to Sitka throughout the duration of our study in contrast to cruise ships boarded from Skagway, which followed different routes to Ketchikan. In 2008, cruise ships traveled through inside waters to Ketchikan, whereas in 2009 ships ventured into outside waters.

Figure 2. (Photo) The observer was stationed inside a gated area at the center of the bow of the cruise ship.
NPS photograph

Methods

Observations of encounters between cruise ships and humpback whales in GLBA and adjacent waters were conducted from May to September, 2008 and 2009, from the bow of six different Holland America cruise ships. The observer spent two nights on board cruise ships, boarding in Skagway or Juneau the day before a ship's scheduled arrival into the park and disembarking in Ketchikan or Sitka (*Figure 1*). The observer coordinated with agents from the Holland America Line, Cruise Line Agencies of Alaska and U.S. Customs and Border Protection on embarkation and disembarkation procedures.

Day 1. Once onboard the cruise ship, the observer coordinated with the chief officer to obtain a hand-held radio. The radio was used by the observer at the bow to communicate with officers on the bridge in the event a whale strike was imminent.

Day 2. The observer proceeded to the bow when the cruise ship was in Icy Strait, and depending on daylight, began observations as early as 4 am (*Figure 2*). Once at the bow, laser range finder binoculars and hand-held binoculars were used to look for whales. A hand-held GPS unit was used to record both the ship track during observations and the geographic location of the ship when a whale was observed (*Figure*

Figure 3. Range finder binoculars and a hand-held GPS unit were used to collect distance and location data of whales that surfaced near cruise ships.

3). When a whale was observed, distance and bearing as determined from the laser range finder binoculars were recorded onto a datasheet and later entered into a Microsoft Access database. Observations were not conducted when ships were in the upper west arm north of Composite Island because whales are rarely sighted in these waters, and because it was an opportunity for the observer to take a break. Depending on the route taken by a cruise ship, observations continued as daylight allowed in Cross Sound or Chatham Strait (*Figure 4*).

Day 3. Upon arrival to Ketchikan or Sitka, the observer met with agents from U.S. Customs and Border Protection and Cruise Line Agencies of Alaska before disembarking from the ship. The same procedures were followed for each cruise.

For results presented here, encounters at distances less than 100 yards (90 m) were considered close encounters. Future analysis will be directed at measuring whale response times to the presence of cruise ships to improve our understanding of close encounters.

Results and Discussion

A total of 49 trips were taken in 2008 and 2009. Ships typically spent nine to ten hours in the park. More than 300 hours of observation were completed during all types of weather conditions, and more than 300 encounters were recorded. The majority of encounters between ships and whales were observed at distances greater than 100 yards (90 m). Close encounters between ships and whales occurred in Icy Strait near the entrance to the park and in lower portions of Glacier Bay (*Figure 5*), which are hotspots of whale abundance (*Noble Hendrix, personal communication 2010*). Results from this study provide the first step to informing park managers where management measures are best applied to protect humpback whales.

Management Implications

Future analysis will be directed at identifying factors that contribute to close encounters between cruise ships and whales, response times of humpback whales to approaching cruise ships, and spatial and temporal patterns of locations where whales surfaced in front of the cruise ship bow. This analysis will also provide further insight into mitigation measures that park managers can adopt to minimize impacts to humpback whales in and around Glacier Bay. Improved understanding of ship and whale encounters can inform managers of where within the park whales are at greatest risk for being negatively impacted by cruise ships and when during the cruise season close encounters most often occur. Also, information on factors that contribute to close encounters and whale response times can further elucidate measures that both cruise operators and managers can take to minimize impacts to whales.

Acknowledgements

Special thanks to N. Drumheller, B. Eichenlaub, C. Gabriele, and J. Nielson for their assistance in this project. Many thanks to the captain and crew of the Holland America cruise ships, agents of the Cruise Line Agencies of Alaska, and U.S. Customs and Border protection authorities for accommodating this project and working with the observer to ensure successful embarkation and disembarkation from cruise ships. Support for this project was provided by Glacier Bay National Park and Preserve, the National Park Service, National Park Foundation, National Fish and Wildlife Foundation, University of Alaska Southeast and University of Washington.

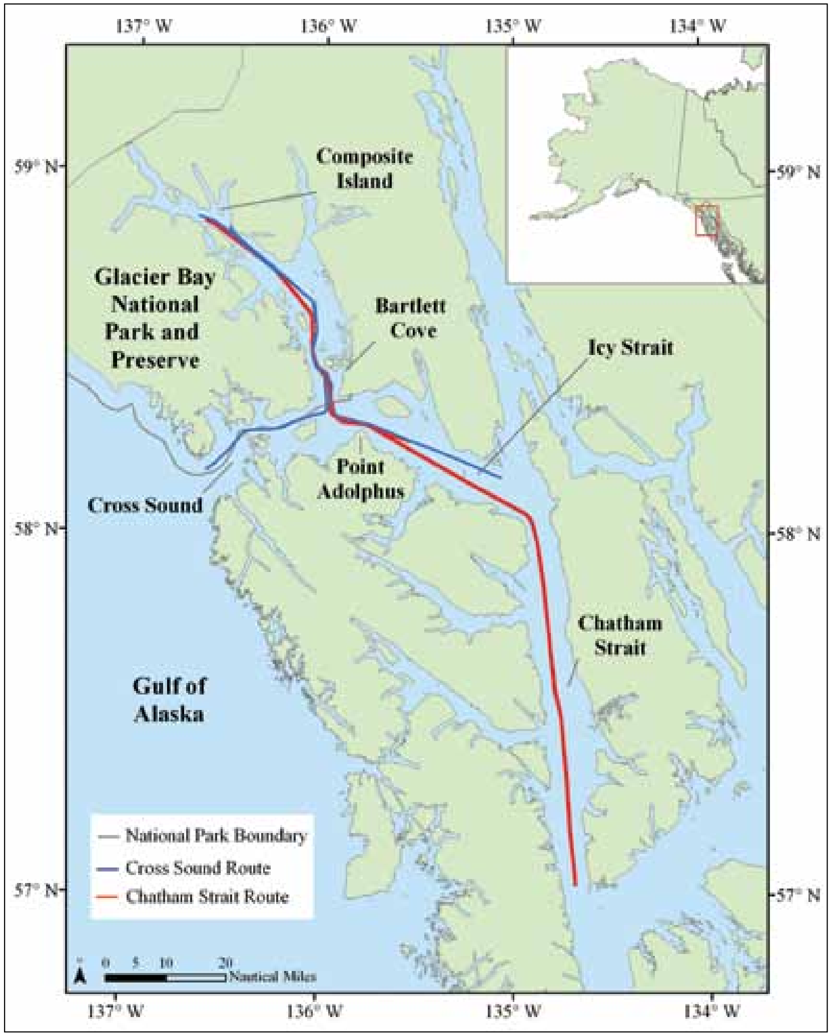

Figure 4. Observations started in Icy Strait, as daylight allowed, and ended in Cross Sound, before ships entered the Gulf of Alaska or in Chatham Strait. The observer did not conduct observations north of Composite Island in Glacier Bay.

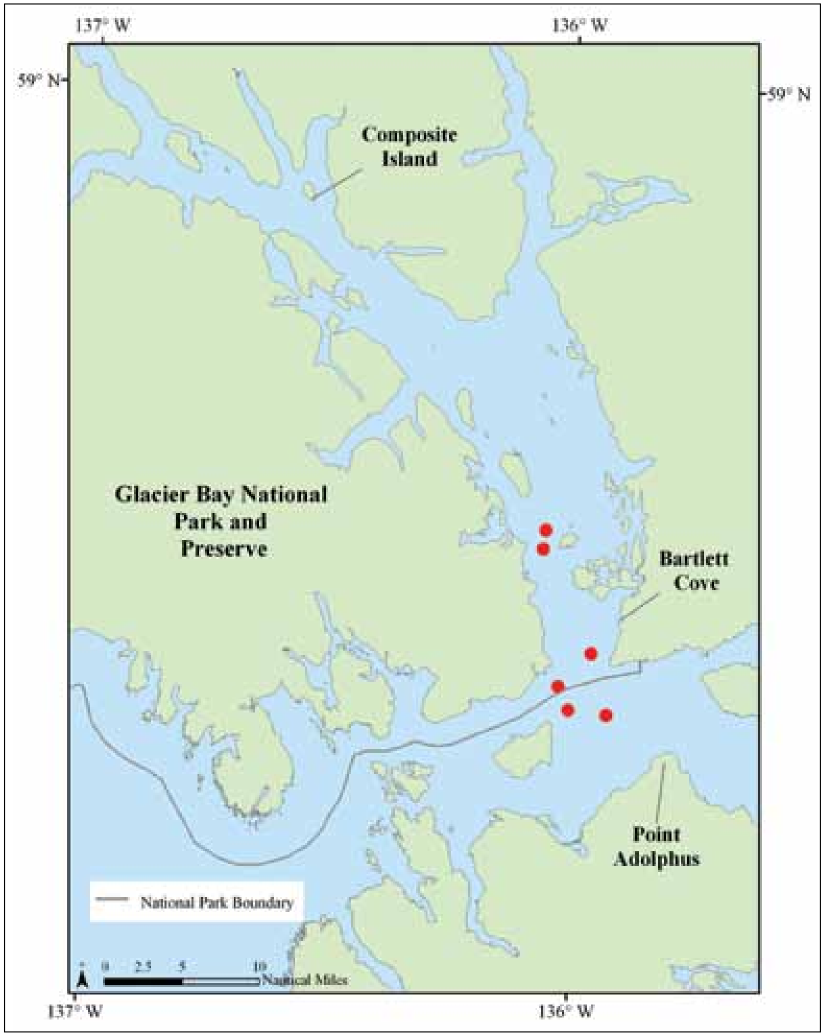

Figure 5. Red dots indicate observations of whales that came within 100 yards (90 m) of the bow of cruise ships during the 2008 and 2009 study period. Close encounters were concentrated around the entrance of the park and in lower portions of the park.

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Effects of Cruise Ship Emissions on Air Quality and Terrestrial Vegetation in Southeast Alaska

By Linda Geiser, David Schirokauer, Andrzej Bytnerowicz, Karen Dillman, and Mark Fenn

Abstract

Increased tourism in Southeast Alaska has raised concerns about the levels and ecological effects of air pollutants emitted by cruise ships in dock and in transit. A multi-agency, regional monitoring program is in place to measure regional and local air pollutants accumulated by vegetation and in deposition. Early results suggest that nitrogen and sulfur oxides, and deposition of sulfur, lead, zinc and vanadium are elevated in Klondike Gold Rush National Historical Park (KLGO) and the adjacent Skagway municipality. Nitrogen and sulfur deposition were elevated at Sitka National Historical Park. Ten-year re-measurements from KLGO and Skagway provide evidence of increasing nitrogen and decreasing lead and nickel deposition, consistent with increased cruise ship port time and the discontinuation of uncontained mining ore transfers in Skagway harbor. Strongest pollution zones correspond with highest human population densities.

Introduction

Increased cruise-ship tourism in Southeast Alaska has been accompanied by increasing concerns about air pollution (*Furbish et al. 2000*). Combustion of low-grade marine fuels releases nitrogen and sulfur oxides, poly-cyclic aromatic hydrocarbons, and metals (*Graw et al., this issue*). In Skagway, frequent summer inversions prevent dispersal of emissions from in port operation of diesel and bunker fuel generators, resulting in noticeable haze and odors (*Figure 1*). Ships in transit in the narrow fjords of Glacier Bay National Park and Preserve (GLBA) and Tracy Arm-Fords Terror Wilderness of the Tongass National Forest (TNF) also produce visible plumes. Recently, managers of the TNF, GLBA, Klondike Gold Rush National Historical Park (KLGO), The Municipality of Skagway, and Sitka National Historical Park (SITK) combined resources to establish monitoring plots designed to assess status of and trends in air quality and detect ecological effects on sensitive epiphytic vegetation due to air pollution. Cruise ship emissions are dominant pollution sources at all sites.

Figure 1. Emissions from cruise ships docked in Skagway harbor cause extensive haze and odors in Klondike Gold Rush National Historical park and the Municipality of Skagway. Monitoring is designed to measure levels and ecological effects of pollutants associated with marine fuel combustion.

Photo courtesy of Alaska Department of Environmental Conservation.

Methods

Monitoring was conducted for air pollution concentration, deposition, precipitation chemistry, and vegetation response. Ogawa passive samplers (*Figure 2*) were used to measure ambient concentrations of nitrogen oxide, ammonia and sulfur dioxide gases. Canopy throughfall samplers were used to measure precipitation chemistry of nitrate, ammonium and sulfate ions. Total deposition was characterized from elemental analysis of epiphytic lichens (*Figure 3*), which was compared to clean site ranges for nitrogen, sulfur, and metals. Community surveys of epiphytic lichens were conducted to assess status of sensitive species. Elemental analysis data were compared to TNF baselines (*Dillman et al. 2007*); managers at this forest have maintained a network of about 120 permanent air quality biomonitoring plots since 1989 (*Geiser et al. 1994*).

Results

Work is still on-going but some initial results can be reported.

- One to five cruise ships dock in Skagway harbor each day from May to September. Visible haze pictured in Figure 1 accumulates in the morning on most of these days beginning at the Skagway harbor and spreading up and down Skagway River valley. The odor of diesel fumes can be detected by residents and also by visitors exploring the historic buildings in town and hiking on the trail system.
- Nitrogen oxides were elevated and five to ten times higher in KLGO at Icy Junction and in the Municipality of Skagway along the lower Dewey Lakes Trail compared to GLBA and SITK (*Figure 4*). Sulfur dioxide was elevated in Skagway along Dewey Lakes trail and at Sturgill's Landing but not at other sites.
- The increase in ship traffic over the past ten years is correlated with small increases in nitrogen accumulated in epiphytic vegetation (lichens) at sites close to Skagway harbor (*Figure 6*).
- Sulfur levels associated with adverse effects to sensitive plants were primarily observed in KLGO lichens within 1.2 miles (2 km) of Skagway and at SITK (*Figure 5*).
- Lead, nickel, cadmium, and zinc levels in lichens were within background ranges at most sites, but still strongly elevated at KLGO sites closest to the Skagway harbor, a legacy from historic use of the harbor to transfer lead and zinc ore from open rail cars and trucks to barges (*Figures 5-6*).
- Vanadium, a product of diesel combustion, was very high at sites closest to the Skagway harbor, especially on the forested fjord walls along Dewey Lakes Trail above the harbor (*Figure 6*).

Figure 2. Passive samplers were used to measure ambient concentrations of sulfur dioxide, nitrogen oxides, ammonia, and nitric acid—gaseous pollutants that can be harmful to plants, wildlife and people. Dyea, Klondike Gold Rush National Historical Park.

Figure 3. Levels of pollutants accumulated by lichens can be compared to expected clean-site ranges, and thus indicate pollution-impacted areas. Elevated levels of sulfer and nitrogen are associated with loss of sensitive species. (A) Collecting lichens along Dewey Lakes Trail above Skagway harbor; (B) *Platismatia glauca*; (C) *Hypogymnia enteromorpha*.

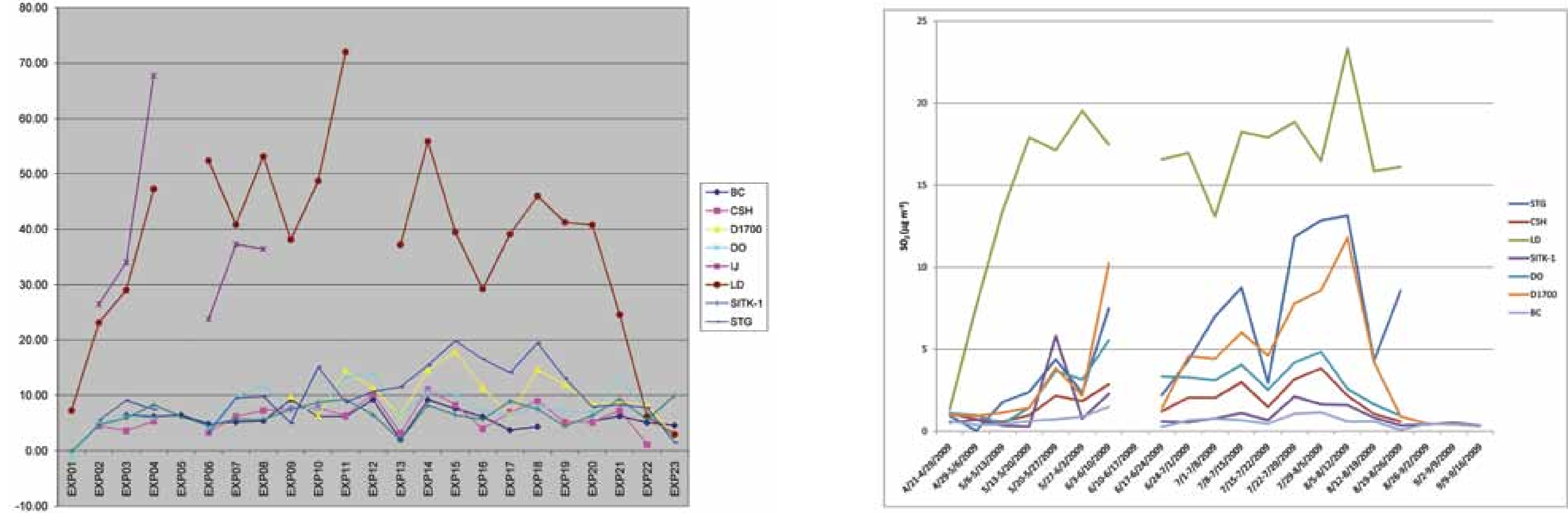

Figure 4. Levels of nitrogen oxides (NO_x, left) attributable to fossil fuel combustion were enhanced at KLGO (IJ = Icy Junction) and the adjacent Municipality of Skagway (LD = Lower Dewey), as well as SITK, but were relatively low at other sites. Levels of sulfur dioxide (SO_2, right) were highest along the Dewey Lakes Trail (LD = Lower Dewey, and D1700) above the Skagway harbor and within the park at Dyea (DO) but were low elsewhere. SO_2 and NO_x are precursors of sulfuric and nitric acids respectively, primary constituents of acid deposition.

Discussion and Conclusions

- The primary pollutants detected through passive instrumental and biological monitors were products of current fossil fuel combustion and historic mine ore transport operations.
- Locally, pollution levels decreased rapidly with distance from point sources (i.e., port activity in Skagway and Sitka). Because the most impacted areas coincide with densest population centers, human health impacts are a potential concern. Lead, nickel and vanadium were significantly enhanced in KLGO/Skagway. Although sulfer and nitrogen oxides were elevated at KLGO/Skagway, they were below levels known to cause direct human health or phytotoxic impacts. However, indirect effects on plant community composition (e.g., from acidic deposition of nitrogen and sulfur compounds) are possible where clean site ranges were exceeded (KLGO/Skagway and SITK).
- The Western Airborne Contaminants Assessment Program study (*Landers et al. 2008*) reported elevated concentrations of nitrogen and certain polycyclic aromatic hydrocarbons (PAHs), both products of combustion, in lichens and conifer needles at Beartrack Cove, GLBA. Elevated nitrogen deposition is spotty as 2008 lichen nitrogen levels at Bartlett Cove, GLBA were within expected clean-site ranges; other pollutants were also within expected clean site ranges. More work is needed to understand pollutants and their depositional patterns in GLBA.
- Increasing nitrogen levels in epiphytic vegetation in KGLO/Skagway correlates with increasing nitrogen oxides from cruise ship emissions and tourism. Although greater trans-Pacific emissions associated with industrial expansion and energy production in Asia and more wildfires emissions from northern Alaska/Canada could contribute to background regional nitrogen oxide levels, nitrogen accumulated by epiphytes from TNF background sites did not increase significantly. Sources contributing to elevated ammonium sulfates in fine particulates at the Petersburg, Alaska, IMPROVE monitoring during the past 10 years have not been identified. As evidenced by the continuing widespread distribution of sensitive epiphytes across the TNF (*Dillman 2004*), there is as yet no evidence of blanket adverse ecological effects from nitrogen or sulfur deposition in Southeast Alaska.

Management Implications

- Reducing cruise ship emissions would have beneficial effects on visitor experiences of visibility and odor. In Skagway, it would also reduce potential human health effects from combustion-related air pollutants such as fine particulates, PAHs, and metals.
- Because pollutant concentrations fall off rapidly

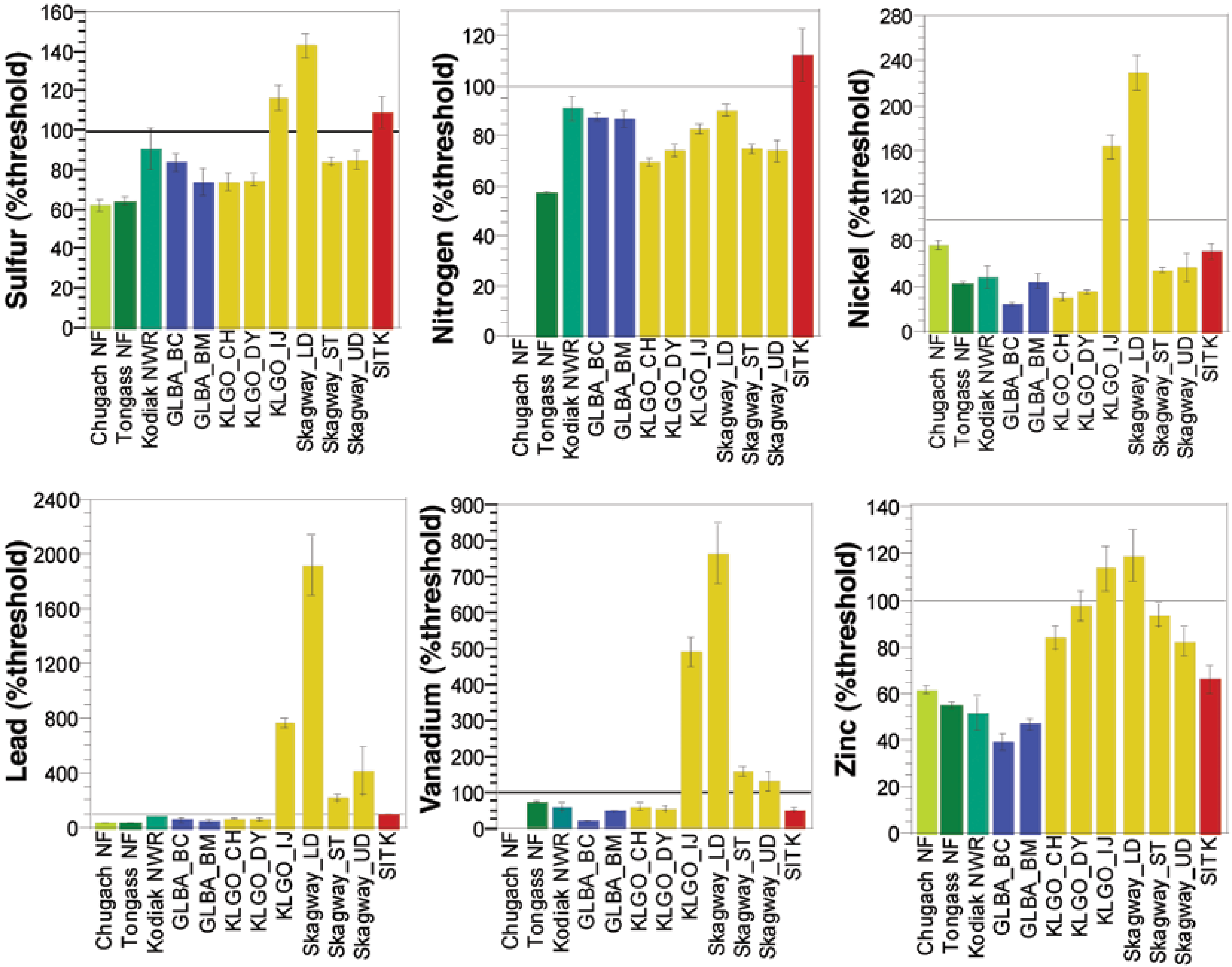

Figure 5. 2008 levels of sulfur, nitrogen and metals in lichens of Southeast Alaska's national parks (GLBA, KLGO, SITK) and at sites in the Municipality of Skagway were higher than levels at sites in the surrounding Tongass and Chugach National Forests or Kodiak National Wildlife Refuge. Nickel, lead, and vanadium were very high at KLGO and Skagway sites closest to the harbor. Horizontal lines indicate clean-site thresholds for the Tongass National Forest established by Dillman et al. 2007.

with distance from sources, the worst impacts can be expected in locations close to docking areas or where topographic and meteorological conditions frequently combine to trap emissions close to the ground.

- Nitrogen and sulfur containing pollutants are quickly processed compared to many metals, which have a much longer residence time (decades vs. years) in soils and vegetation.
- Continued monitoring of established sites can be used to verify effectiveness of air resource management policies. It could be important to measure particulate matter levels because nitrogen oxides, sulfur dioxide and ammonia form sulfate and nitrate aerosols which are hazardous to inhale and are precursors of acidic deposition.

Acknowledgements

We thank the NPS Southeast Alaska Inventory and Monitoring Program, NPS Air Resources Division, NPS Southeast Alaska Coastal Cluster, Municipality of Skagway, US Forest Service Alaska Region Air Resource Management Program, and the Tongass National Forest Wilderness Management Program for providing funding for this project. Many competent field technicians and staff from Southeast Alaska contributed to making this project a success. Most of all, the partnership between the US Forest Service and the National Park Service made this work possible.

For further info, please visit: http://gis.nacse.org/lichenair

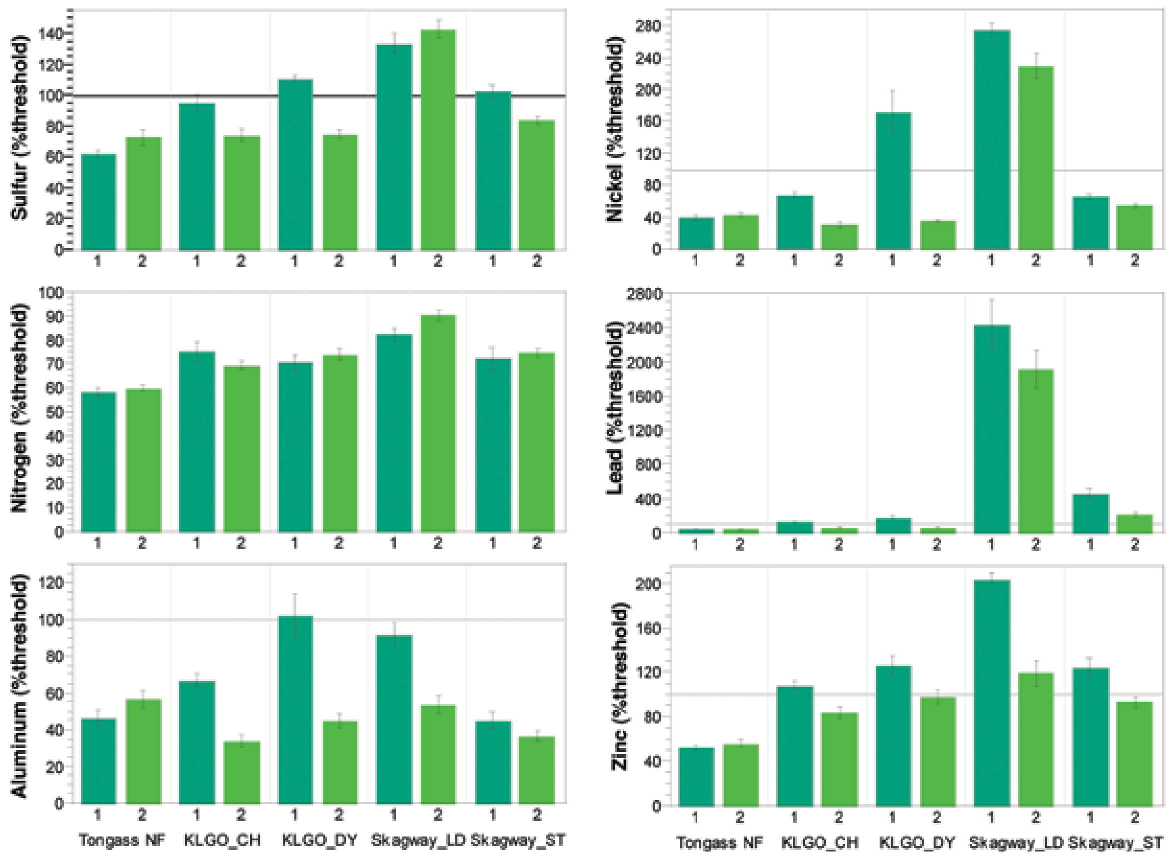

Figure 6. Levels of legacy lead, nickel and zinc in vegetation (epiphytic lichens) samples from the Municipality of Skagway and KLGO decreased over the past 10 years (1 = 1998, 2 = 2008). Lower aluminum indicates generally lower dust levels in KGLO and Skagway. By contrast, nitrogen increased slightly at most sites and sulfur declined at all sites except the site closest to the Skagway terminal. Horizontal lines indicate clean-site thresholds for the Tongass National Forest established by Dillman et al. 2007.

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Air Pollution Emissions from Tourist Activities in Klondike Gold Rush National Historical Park

By Richard Graw, Albert Faure, and
David Schirokauer

Abstract

Each summer, tens of thousands of people visit Klondike Gold Rush National Historical Park. During the height of the tourist season, up to five large cruise ships arrive daily in the Skagway harbor where they are met by tour buses and trains to take them on historical and scenic rides in the park and beyond. While docked in Skagway, each cruise ship continues to provide electrical power, heat and steam to passengers and crew by operating their engines and boilers for a period of 10 to 14 hours. Additionally, the waste generated in town is incinerated at the municipal incinerator. As a result, approximately 1,100 lbs/hr of nitrogen oxides (NO_x) and 800 lbs/hr of sulfur dioxide (SO_2) are emitted in Skagway, the majority of which is emitted by cruise ships. The amount of NO_x and SO_2 emitted by these ships is not directly related to the number of ships, but rather engine power output, fuel consumption rates, and fuel characteristics. Air pollution emission rates of visiting cruise ships are expected to decrease with the implementation of the Emission Control Area (ECA) recently adopted by the International Marine Organization (IMO).

Figure 1. Idling cruise ship emissions are visible during inversions.

Photograph by Rick Graw

Introduction

During the height of the 2008 tourist season, the National Park Service, together with the U.S. Forest Service, conducted a study of the effects of air pollution on the ecosystem of Klondike Gold Rush National Historical Park and the Tongass National Forest. To assess impacts of current and future scenarios, an air quality dispersion modeling analysis is being conducted. The dispersion model simulates the transport and dispersion from user-specified sources, and quantifies the concentration and deposition rates of these pollutants. Thus, the user must specify the emission rate and release characteristics of each emission source. This portion of the study presents the estimated emission rates of NO_x and SO_2 from cruise ships, buses, trains, and the municipal incinerator and offers some insights into their wide range of magnitude and contribution to total emissions.

Methods

Emissions were provided by individual emission source or estimated using emission factors and source-specific operating characteristics (e.g., fuel type, hours of operation, etc.). An emission factor is a representative value that relates the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant (e.g., pounds of NO_x per gallon of fuel burned). Emission factors were obtained from the U.S. Environmental Protection Agency (*1996, 1997, 1998*), and the American Bus Association (*2006*). In the absence of direct measurements and emission factors, the International Maritime Organization (IMO) NO_x regulatory limit (*1997*) was used as a surrogate.

Results

Figure 2 illustrates the mean daily emission rate of NO_x and SO_2 from each emission source category and the variation throughout the week. Cruise ships were the greatest source of pollutants, emitting as much as 800 lbs/hr of NO_x and SO_2 each, during mid week, and decreasing dramatically on weekends. Trains were the next largest source of SO_2, emitting as much as 180 lbs/hr, but substantially less NO_x. The municipal incinerator and buses emitted relatively small amounts of NO_x and SO_2.

The amount of SO_2 and NO_x emitted from individual cruise ships varies substantially. Figures 3 and 4 illustrate the estimated hourly emission rates of SO_2 and NO_x, respectively, from 22 cruise ships and an Alaska Marine Highway ferry that visited Skagway during the study period. The ship names are listed along the bottom axis, in increasing order of capacity from left to right. The capacity, indicated by the red dots, ranged from 117 to 4,138 passengers and crew. The SO_2 emission rate (*Figure 3*) varied from 1 to 446 lbs/hr. The NO_x emission rates (*Figure 4*) varied from 11 to 314 lbs/hr.

While there is a general trend of increasing SO_2 emissions with ship capacity, there is wide variation amongst individual ships. The emission rate of SO_2 is determined from the sulfur content of the fuel, fuel

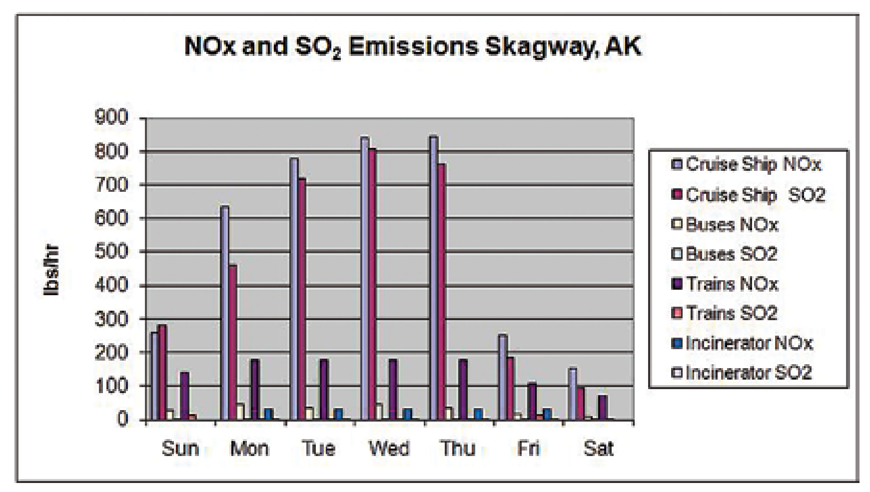

Figure 2. Daily variation in NO_x and SO_2 emissions in Skagway, during a typical week of the 2008 season.

density, and fuel consumption rate. Fuel consumption is related to the power and steam demands of each ship, as needed to provide electricity, heat, and hot water.

Interestingly, ships with similar capacity may have widely varying emission rates of SO_2. Consider the following two ships: Princess Cruise Lines' *Diamond Princess*, with a capacity of 4,138 passengers and crew, and Royal Caribbean's *Serenade of the Seas*, with a capacity of 3,300 passengers and crew. The *Diamond Princess* has a fuel consumption rate of 1,144 gal/hr, whereas the *Serenade of the Seas* has a fuel consumption rate of 745 gal/hr. The two ships also use different fuels containing widely varying amounts of sulfur (2.5% sulfur by weight compared with 0.05% sulfur by weight). As a result, the Diamond Princess emits 446 lbs/hr of SO_2, whereas the Serenade of the Seas emits only 5 lbs/hr of SO_2.

As the case with SO_2, NO_x emissions generally increase with ship size, but vary widely amongst cruise ship. Emissions of NO_x result from both fuel-bound nitrogen and the nitrogen contained in the combustion air. The emission rate of NO_x is a function of the fuel type and rate of fuel combustion, which increase in proportion to power demand.

Discussion and Conclusions

Cruise ships account for the majority of NO_x and SO_2 emissions in Skagway, but vary in amounts depending upon the number of ships docked in port. However, the amount of NO_x and SO_2 emitted by each ship can vary greatly, depending upon engine power demands, fuel type, fuel consumption rates, and the sulfur content of the fuel.

Emissions from cruise ships are regulated by the IMO. Recently, IMO adopted the U.S.-Canadian petition to establish all waters within 200 nautical miles of the U.S. and Canadian coast line as an Emission Control Area (*EPA 2010*). As a result, emissions from these large vessels will be regulated to reduce SO_2 and NO_x in the future.

Management Implications

In recent years, park managers have considered the air pollution impacts from the increasing number of cruise ships visiting Alaska parks. While it seems appropriate from a management perspective that limiting the number of ships would limit the air pollution impacts, an investigation into the emissions released from cruise ships has found cruise ships can vary widely in the amount of SO_2 and NO_x emitted. The study found that emissions of air pollutants from cruise ships are dependent upon engine power demands, fuel characteristics, fuel consumption rates, and applicable regulations. Thus, these insights offer new options for addressing concerns about air pollution while not necessarily limiting the number of cruise ships visiting parks. Additional modeling efforts may be able to refine the relationships between emissions, air quality, and impacts to natural resources.

A full report of the Air Pollution Emission Inventory from Skagway, Alaska, during the 2008 tourist season can be found on the Alaska Department of Environmental Conservation web site at http://dec.alaska.gov/water/cruise_ships/pdfs/Skagway2008_Final_Emissions_Report.pdf.

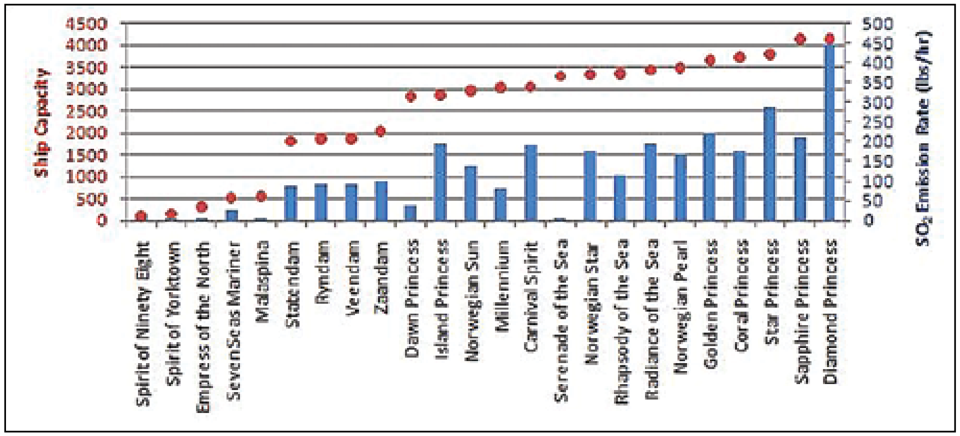

Figure 3. Emission rates of SO_2 from cruise ships and an Alaska Marine Highway ferry (*Malaspina*).

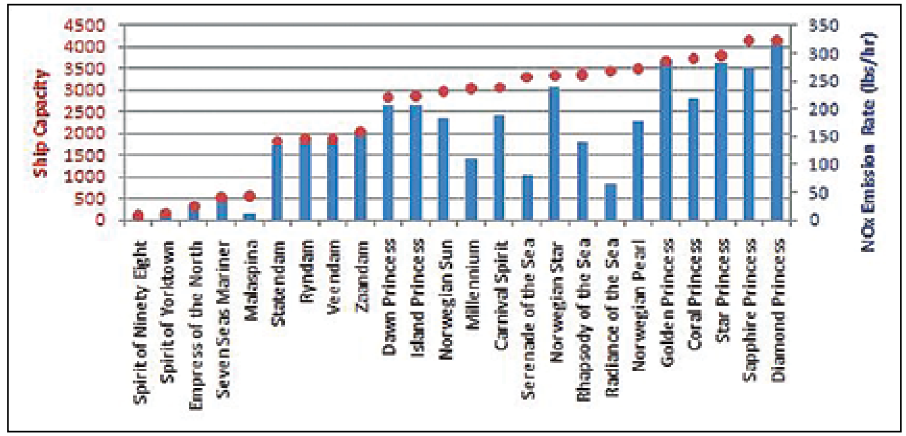

Figure 4. Emissions rates of NO_x from cruise ships and an Alaska Marine Highway ferry (*Malaspina*).

Photograph by Rick Graw

Figure 5. Inversion above Skagway.

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Estimating Population-level Consequences to Humpback Whales Under Different Levels of Cruise Ship Entry Quotas

By Scott M. Gende and A. Noble Hendrix

Across the National Park Service, managers struggle with decisions regarding levels of allowable visitation. The NPS mandates that superintendents and other resource managers prohibit activities, including those by concessionaires, that will 'significantly impact' or 'impair' park resources. Yet, depending upon the resource of interest, this can be a difficult standard to follow. In many cases, the dynamics of ecological processes, population numbers, or community structure can be so naturally variable that linking a visitor's activity to changes in a population may not be ascertained with any certainty until impairment has already occurred. Even when national standards defining impairment already exist, such as for air and water quality, the decision may be somewhat ambiguous. For example, a number of streams in Glacier Bay would exceed the Environmental Protection Agency's standards for impairment based on the metric of suspended particulate matter even though these streams are silt laden due only to the natural process of de-glaciation.

Figure 1. An endangered humpback whale dives near Glacier Bay National Park and Preserve. Individual humpback whales have been photographically identified since the 1970s under a long term monitoring program in and around the park. Working in collaboration with researchers from the University of Alaska Southeast, Sitka Campus and others, sighting of over 1,500 whales have been compiled in southeastern Alaska, forming the basis of the mark-recapture population abundance estimates used for population simulations presented here. Details of the mark-recapture study will be submitted for peer-reviewed scientific publication in late 2010 (*Hendrix et al. in prep*). For more information on life history studies of these long-lived whales, see http://www.alaskahumpbacks.org

NPS photograph

Despite the ambiguity in the definition of impairment and its proper application, few managers would argue that an action resulting in a decrease in the natural trajectory of a population of an endangered species constitutes 'significant impact' and therefore be prohibited. Thus, a fundamental question related to humpback whales and cruise ship entry quotas is: How will increases in cruise ship quotas affect the population dynamics of endangered humpback whales in Glacier Bay based on what we currently know about ship-whale interactions?

In order to answer this question, we used a model of whale population dynamics forecasted to 2028 under different levels of cruise ship traffic. The model required us to specify the mechanism by which cruise ships could alter population dynamics of humpback whales, and then an estimate of how this process would change if ship entries increase. As several authors have described in accompanying articles, the two most direct mechanisms by which cruise ships impact humpback whales is via acoustical disturbance or severe injury or death as a result of collisions. Acoustical impacts likely occur on a daily basis, as most whales in Glacier Bay and surrounding waters hear the ships from many miles away. Less clear is how many, or to what degree, whales alter their behavior in response to the noise generated from cruise ships. Isolating the effects of cruise ship-generated noise on changes in habitat use or movements to other areas will be difficult owing to factors such as changes in fish abundance and distribution, which affect whale movements and behavior on a daily and seasonal basis. As a result, relating these levels of acoustical exposure to some population level metric, such as lowered survival rate or changes in reproduction, is particularly difficult. In contrast, collisions between cruise ships and whales have a more direct link to fitness (survival) because, given the size and speed of the ships, it is likely that any direct collision will result in a severe injury or death to the whale. Thus, we focused only on the relationship between ship entries and probability of collision to estimate how changes in ship quotas may significantly impact the population dynamics of humpback whales using Glacier Bay and surrounding waters.

To do so we needed to estimate four things. First, we needed to know how many whales are using (status) and have used (trend) Glacier Bay in order to forecast future population levels. Second, we needed to estimate the level of 'mixing' among areas in Southeast Alaska. For example, humpback whales in Alaska generally migrate to Hawaii

Glacier Bay - 2028				
Ship-Whale Collision Detection Probablity	100%	100%	10%	10%
Cruise Ship Entries to GLBA	139	184	139	184
Abundance	2098 (149, 5219)	2097 (149, 5219)	2065 (192, 5315)	2073 (189, 5217)
Trend	5.49% (-7.4%, 10.1%)	5.49% (-7.42%, 10.1%)	5.46% (-6.00%, 10.1%)	5.44% (-6.06%, 10.1%)
Additional Collisions		1.07 (0.3)		10.6 (5.17)
Additional Loss of Whales		1.53 (0.00, 6.46)		15.2 (3.79, 35.71)

Figure 2. Projected estimates of abundance and trend of humpback whales in 2028 under different ship-whale collision detection levels (10% detected vs. 100% detected) and peak season quotas of 139 ship entries (2004 levels) vs. 184 entries (maximum allowable under the Glacier Bay Vessel Quota and Operating Requirements EIS). Additional collisions indicate the number of ship-whale collisions accrued over 20 years should the NPS allow for 184 vs. 139 entries per year. Additional loss of whales represents the loss to the population as a result of death from collision plus the productivity attributed to those whales had they been able to live and reproduce, for entries of 184 vs. 139. Parenthesis indicate the lower and upper levels of a 95% probability interval around the median.

each year for reproductive activities, returning to Alaska in early spring. Individuals may spend all summer in Glacier Bay, migrate to Hawaii, and then return to spend all summer in another area of Alaska, such as Sitka Sound or Frederick Sound. Or, they may move among areas in Alaska during the summer. This annual level of 'fidelity' to an area is important to know. If little migration occurs to/from areas in Alaska any incidental mortality (such as from an increase in collisions with cruise ships), will affect the whales in that location only. If whales commonly migrate among areas, the population can buffer the incidental mortality via migration of other adults into the park.

Third, we needed to estimate the annual survival rate of whales using Glacier Bay. The annual survival rate will incorporate all sources of mortality, including natural causes of death such as from predation, or anthropogenic sources of mortality, such as entanglements with fishing gear, to generate an estimate of the probability that an adult will survive from one year to the next. This estimate forms the base survival rate upon which any additional mortality, such as more whale deaths as a result of permitting higher numbers of cruise ships into the dense population of whales using Glacier Bay, would lower the base survival rate. Fourth and final, we needed to estimate the rate at which whales are struck by ships under existing entry quotas.

To generate quantitative estimates of abundance, fidelity, and survival, we used a modified 'mark-recapture' model, using a long-term photographic monitoring data set. Researchers from Glacier Bay, the University of Alaska Sitka, and several other institutions have, for many years, photographed the flukes of humpback whales in Glacier Bay and several other aggregation hotspots to identify individuals and track their movements (*Figure 1*). This data set has been used to generate abundance and trend estimates previously (*Straley et al. 2009*), and we updated these estimates under a probability-based framework which allows explicit incorporation of uncertainty.

We also estimated the rate of collisions between cruise ships and whales. Based on 1 known collision that occurred in 2001, another (assumed) collision in 2004, and 1694 entries of cruise ships over the period of 2001 to 2009, we estimated the rate of collisions as 0.00118 (collisions per ship entry). However, this estimate is low because not all collisions are detected. Thus, we further modeled the probability of detecting a collision given that one occurred. If we assume that all struck whales are detected, i.e., 100% detection probability, then the rate of collisions is 0.00118. However, if only 10% of the actual collisions are detected, then the rate of collisions is 0.0118. The assumption of a 10% detection rate likely overestimates the number of whales struck (20 between 2001 and 2009) but provides a worst case scenario on the impacts to the population.

Our results from the model simulating population dynamics under different levels of cruise ships and detection probability are summarized in Figure 2. The results demonstrate that even under the most conservative assumptions and after explicitly incorporating uncertainty, increasing the number of cruise ships to Glacier Bay will not significantly impact the population dynamics of humpback whales. For example, assuming only 10% of struck whales are detected, the median trend estimate under the maximum number of ship entries (184 per year, for 20 years) differs only slightly from our median trend estimate under conditions of 139 entries and 100% detection probability. This result is due to the low rate of collisions relative to the current increasing population trend (which in turn is due to a high survival rate and high reproductive rate).

So, should Glacier Bay allow increases in cruise ship traffic? It is important to consider the limitations of this modeling exercise. Our effort focused only on the role of collisions between ships and whales and did not include the suite of mechanisms by which ships can impact humpback whales, including acoustical disturbance. It is also possible that the trend of Glacier Bay may change over the next 20 years, which may not support the current rate of growth for this population. Continued support of the whale monitoring program will be important in order to quantify and track these changes. However, the population of humpback whales is robust. At its current rate and assuming no other conditions change, an increase in ship traffic will not likely significantly impact or impair the population of whales using Glacier Bay. Park managers will need to consider the benefits of visitation with the potential loss of whales, even if the population dynamics are not likely to change.

NPS photograph

Figure 3. Breaching may be one form of communication among humpback whales.

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An Overview of Cruise Ship Management in Glacier Bay

By David Nemeth and Kevin Apgar

Introduction

What could be simpler than to manage cruise ships in Glacier Bay? No docking and no shore excursions, just hundreds of thousands of park visitors leaving nothing behind but the gentle lapping of the ships wake, shimmering in the setting sun. If that was ever the view of park managers, it did not last long, as is evidenced by some of the research described in this issue. As you will see, management of cruise ships in Glacier Bay is anything but simple.

Cruise Ship Quotas

Since 1980, cruise ships have been limited to a maximum of 2 ships per day, year round, and to further limitations during the prime season, June 1 to August 31. In 1981, the cruise ship prime season quota was reduced 20% (from 107 to 89) based on concerns over the impact of cruise ships and other vessels on the endangered humpback whale and a related National Marine Fisheries Service biological opinion. There were further prime season quota adjustments in 1985 (102), in 1988 (107), 1996 (139), 2001 (130), 2002 (back to 139), and in 2007, to the current level of 153.

The 2003 Vessel Quotas and Operating Requirement Environmental Impact Statement added a separate seasonal quota of 92 cruise ship entries for May and September, but allows for an increase to 122 (maximum of two per day). About 70 "shoulder season" entries are scheduled each year, which is well below the quota that has remained unchanged.

Figure 1. Cruise ship at Margerie Glacier.

NPS photograph by Tom Vandenberg

Management

Management of cruise ship services has evolved largely in concert with nationwide changes in NPS management of commercial visitor services, with some idiosyncrasies related to the unique nature of these services. Formal permits to the cruise ship companies authorizing their activities were first issued in 1980, essentially grandfathering in the existing cruise lines.

Cruise ship services in Glacier Bay are atypical concession operations in many respects. For example, virtually all of the ships are of foreign registry, most employees on-board are not citizens of the United States, and insurance practices are based primarily on maritime laws and practice. The State of Alaska, U.S. Coast Guard, U.S. Environmental Protection Agency and Federal Maritime Commission are just a few of the government agencies who have primary responsibilities for oversight of cruise ship operations in U.S. waters. Park management of cruise ship services must take into consideration not only the specific mandate to protect park resources and provide for visitor enjoyment, but also consider the broader legal and regulatory framework under which cruise ships operate.

There are several federal laws related to cruise ship services that are specific to Glacier Bay. These include:

- PL 110-161 Sec. 134, which provides Holland America Line and Princess Cruises the right to continue providing cruise ship services non-competitively, based on use levels prior to 1979.
- PL 104-333 Sec. 703, which limits park authority to impose operating conditions in the areas of air, water, and oil pollution beyond those enforced by other appropriate agencies.

The competitive process used in the award of concession contracts has provided an effective means for the NPS to achieve environmental goals without "imposing operating conditions" prohibited under PL 104-333. Concession contracts authorizing cruise ship services for 2010 through 2019 were recently awarded through a competitive selection process. Companies competed for a contract as well as a fixed number of entries.

Selection criteria included:

1. protection of park resources – air quality, water quality, and underwater sound,
2. the itinerary while in the park and the on-board interpretive program,
3. experience, including past violations and accidents,
4. financial capability,
5. offers of a higher franchise fee, and
6. other environmental issues, including minimizing waste and hazardous materials use.

In 2009, Princess Cruises submitted a proposal that was judged to be the best of six from companies competing for contracts, and Princess was allocated 58 trips, 32 of them under historical rights. Princess proposed the

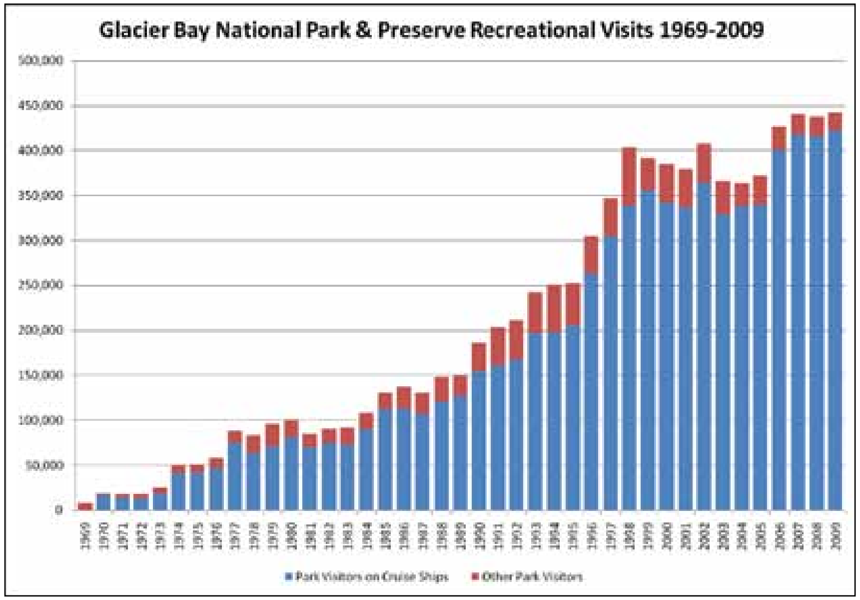
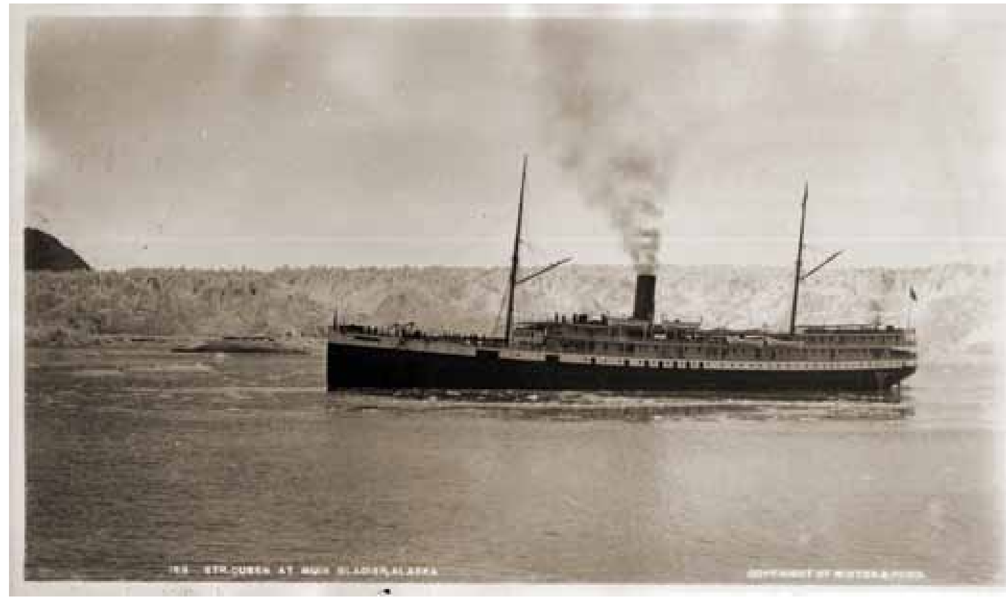


Figure 2. Glacier Bay recreational visits.



Alaska State Library, P87-1724

Figure 3. Steamer *Queen* at Muir Glacier.

use of turbine engines, low sulfur distillate fuel and other strategies for reducing air pollution and a "no discharge" policy to minimize water pollution in Glacier Bay. They committed to underwater sound signature testing, developed a "whale strike avoidance program," offered a number of enhancements to the interpretive/educational program focused on Glacier Bay, and proposed a franchise fee of $12 per passenger, $5 above the minimum. The remaining contracts and trips were awarded to Holland America Line (65, of which 39 were under historical rights), Cruise West (8), and Norwegian Cruise Line (22).

One key point is that the cruise operators voluntarily proposed elements to minimize impacts in the areas of air, water, and oil pollution as part of a competitive selection process, and the NPS accepted the elements which, in its judgment, would minimize impacts in the areas of air, water, and oil pollution. These elements proposed by the operators were added to their final concession contracts, but NPS did not impose operating conditions in the areas of air, water, and oil pollution beyond those enforced by other appropriate agencies, as prohibited under PL 104-333.

Visitor Experience and the Interpretive Program

From the late 1960s to the 1980s a day on a cruise ship in Glacier Bay was much the same as the days spent outside the park, organized around games such as bingo, auctions, dance lessons, life boat drills, gambling and meals. Today, the day in the park is organized to showcase the significant resources and purpose of the park, while minimizing competition from unrelated activities. The cruise ship itinerary is a significant element in ensuring that passengers have a reasonable opportunity to enjoy, learn about and experience the park. A good itinerary helps promote a positive visitor experience; a poor itinerary undermines it. As with impacts to air, water and oil pollution, the competitive selection process was used to encourage operators to suggest optimal itineraries for the day spent in the park.

In 1969 Park Ranger Bruce Paige climbed aboard the *m/v Mariposa* to provide visitors with information about the park, initiating a program that now forms the backbone of the park interpretive operation. The NPS considers it essential that cruise ship visitors to Glacier Bay be given an opportunity to learn about the area during their visit. In furtherance of this, cruise lines are given the option of providing their own interpretive program, meeting NPS minimum standards, or utilizing an NPS interpretive program on a cost recovery basis. To date, all cruise lines have elected to participate in the NPS program. The NPS program consists of live on-board commentary over the ship's public address system, formal auditorium programs, special children's programs and activities, scheduled special interest events, informal question and answer opportunities and access to park reference materials through Alaska Geographic, a non-profit cooperating association. The total (2010) program cost is about $660,000 or about $1.58 per passenger. In addition, through the competitive selection process, operators proposed enhancements to the NPS interpretive program, including supplemental

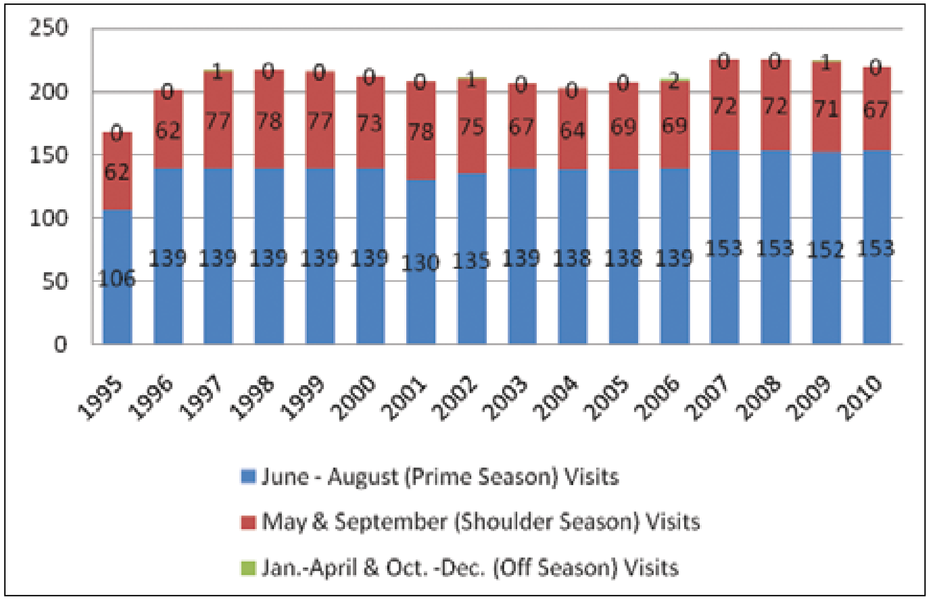


Figure 4. Glacier Bay cruise ship visits during 1995-2010.

NPS photograph

Figure 5. *Norwegian Pearl* in Glacier Bay.

pre-visit lectures, videos, podcasts and cultural programs.

Operations

In addition to general operational requirements imposed by state and federal agencies, cruise lines are also subject to park specific regulations as well as each operator's specific concession contract provisions. Park regulations are available at http://www.nps.gov/glba/parkmgmt/regs.htm (36 CFR Part 13, Subpart N). Each of the cruise ship concession contracts are available at: http://www.nps.gov/glba/parkmgmt/cruise-ships.htm.

Cruise ships are also subject to the regulatory vessel speed limits in "whale waters", exclusions from areas closed to motor vessels, and approach limits to specific islands important for bird nesting and sea lion haul-out.

Compliance

The NPS supplements the work of lead agencies, such as the U.S. Coast Guard and the State of Alaska, in monitoring concessioner compliance with general regulatory requirements. For example, park staff monitor cruise ship exhaust stack opacity based on assimilated State of Alaska air quality statutes (*Alaska 18AAC50, 2005*). Park staff also work with the State of Alaska Ocean Ranger Program, which is funded by a passenger "head tax", to insure that special requirements for Glacier Bay are among the areas monitored by the technical specialists ("Ocean Rangers").

Fees

The first cruise ship permits in 1980 required payment of a total fee of $25 per vessel entry. The required fee was increased over the years to a minimum of $7 per person for the 2010 concession contracts. An offer of a higher fee was also a selection factor in the competitive award of cruise ship contracts and use days. Three of the cruise lines offered $12 per passenger, which the NPS accepted. Eighty percent of this money, which totaled nearly $5 million dollars in 2010, is retained by the park and used to pay for park operations, including resource management, research and other park programs. The other 20% is retained by the Washington D.C. office of the NPS and distributed throughout the national park system.

Conclusion

Cruise ship management in Glacier Bay has evolved significantly over the last 40 years, driven by new laws and regulations, better understanding of potential impacts and through positive partnerships with the cruise industry. In addition, the competitive process for allocating cruise ship services has been a successful tool for minimizing cruise ship air, water, and oil pollution, improving the visitor experience on the ships, and through franchise fees providing funds for resource management, research and other park programs.

Effects of Cruise Ships on Visitor Experiences in Glacier Bay National Park and Preserve

By Jane E. Swanson and Mark E. Vande Kamp

Abstract

Visitors to Glacier Bay were asked about their experiences with cruise ships and other mechanized transport via a mail survey. Findings indicated that cruise ships detracted from visitor trip enjoyment, specific dimensions of trip experience and enjoyment of the Margerie and Grand Pacific glaciers. Ratings of overall trip satisfaction showed no effects of cruise ships. Experiences with one form of transport (e.g., cruise ships, tour boats, or aircraft) affected both the perceived effects of that form, and of other forms. Increasing seasonal use days to 184 in Glacier Bay National Park and Preserve is estimated to produce few and relatively small changes.

Introduction

In the last few years, cruise ships have brought 95-97% of the approximately 400,000 yearly visitors to Glacier Bay National Park and Preserve (GLBA). In an effort to understand how cruise ships in Glacier Bay affect visitors' experiences (excluding the benefits of cruise ships as a mode of transport), park managers initiated a two-year research program. Year 1, summer 2007, research gathered information needed to develop and administer an effective quantitative mail survey in Year 2, summer 2008. A mail survey was planned because it was a cost-effective and flexible way of collecting visitor experience data that can provide population estimates. Also in Year 2, qualitative interviews with park visitors were conducted to complement and inform the results of the quantitative mail survey.

Figure 1. Cruise ship passengers were contacted as they disembarked in Juneau.

University of Washington photograph by Mark Vande Kamp

The objectives of the research program were to answer the following questions:

1. How do cruise ships affect, if at all, visitor experiences in Glacier Bay?
   a. Which dimensions of visitor experiences in Glacier Bay, if any, do cruise ships affect?
   b. If cruise ships affect visitor experiences in Glacier Bay, which features of cruise ships have effects?
2. What are the estimated effects for park visitors under the Record of Decision maximum use level of two cruise ships in the bay, every day?
3. How do the effects on visitor experiences in Glacier Bay compare for cruise ships and other forms of mechanized transport?

People visit Glacier Bay by a variety of means (e.g., cruise ship, kayak, park day boat, etc.), and most have the potential to encounter cruise ships during their trips. However, the geographical separation between the areas used by most single-day kayakers and cruise ships and the relatively small number of such visitors made the likelihood of effects low enough to warrant exclusion of single-day kayakers. Targeted visitors included: 1) cruise ship passengers, 2) park day boat passengers, 3) tour boat passengers, 4) charter boat passengers, 5) private vessel boaters, and 6) multi-day backcountry users.

The limited research on cruise ships and their effects has not established conventional measures for the effects of cruise ships. This research included a range of measures to 1) increase the likelihood that the research would be both sensitive to effects, and relevant to managers and/or visitors, and 2) provide measures of specific effects and of the strength and extent of those effects. For example, if cruise ships were found to affect one or two dimensions of visitor experiences but none of the overall measures, it would suggest that although effects were present, they were limited in their scope.

Method

Between June 27, 2008 and August 31, 2008, visitors in the six user groups were contacted in either Juneau or Bartlett Cove and asked to participate in the study. Those agreeing were sent a questionnaire within one week of the initial contact. Follow-up mailings resulted in response rates ranging from 69.3% to 85.1% across the six user groups. Samples (n ranged from 87 to 450) were examined for non-response bias and representativeness, and if needed, were statistically weighted to represent the target populations.

Information collected during the initial contact described the participant and his/her travelling party, and was used in non-response analyses. The mail questionnaires asked about 1) trip characteristics including length of stay, activities, weather, and importance of different trip experiences; 2) general demographic information including age, gender, education, and ethnicity; 3) exposure to different types of mechanized transport; and 4) effects of exposure to different types of mechanized transport.

Results

Exposure to cruise ships

Excluding cruise ship passengers, 75% or more of visitors reported seeing or hearing cruise ships during

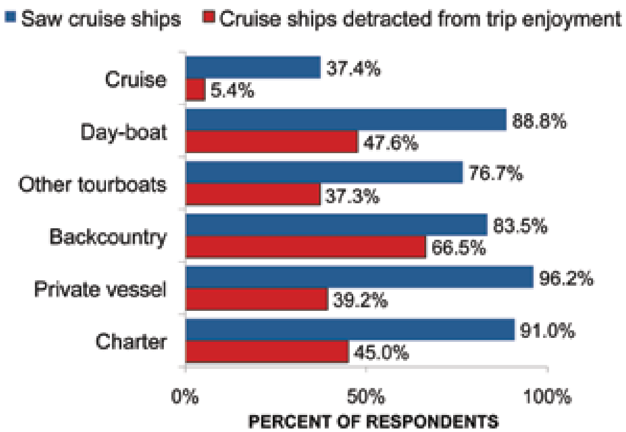


Figure 2. Percent of respondents in each user group exposed to cruise ships and that reported cruise ships detracted from their trip enjoyment.

University of Washington photograph by Mark Vande Kamp

their visit to Glacier Bay proper. The percentage of cruise ship passengers that reported seeing or hearing another cruise ship was smaller (37%), because it was only possible for them to hear or see another cruise ship on days when two-cruise ships were in the bay. The average number of days spent in Glacier Bay proper ranged from 1.0 for cruise ship passengers to 5.6 for backcountry visitors. Of all visitors who saw or heard cruise ships, half did so on three or fewer days, and half did so for three or fewer hours. Thus for most visitors to Glacier Bay proper, exposure to cruise ships was likely although the exposure was usually short, both in duration and as a percentage of total time spent in the bay.

Effects on trip experience

Although very general measures (i.e., ratings of overall trip enjoyment) did not show effects of cruise ships, measures that asked directly about cruise ship effects on trip enjoyment did. Specifically, in user groups other than cruise ship passengers, the percent of all respondents who reported that cruise ships detracted from their trip enjoyment ranged from 37% to 67% (5% of cruise ship passengers reported such detraction). These reports of negative effects from cruise ships were off-set slightly by a small percentage of visitors in each user group that indicated cruise ships added to their enjoyment.

Similarly, on measures that asked about the effect of seeing cruise ships at Margerie/Grand Pacific glaciers, in four user groups more visitors reported that ships detracted from their enjoyment than reported that cruise ship detracted from trip enjoyment. Detraction at the glaciers did not always result in more general reports of detraction due to cruise ships.

Several dimensions of visitor experiences were identified in the 2007 qualitative study, and rated in the 2008 mail survey for, a) importance, and b) the extent to which cruise ships detracted from them. On average, all dimensions were at least moderately important for all user groups, and on average, seeing or hearing cruise ships never added to any trip dimension. The range of importance and detraction is illustrated by the most discrepant groups (cruise ship passengers and backcountry visitors)(*Figure 3*). Of the six user groups, cruise ship passengers gave trip dimensions the lowest importance ratings and reported the least detraction due to other cruise ships, while backcountry visitors gave the highest importance ratings and reported the most detraction.

For all user groups, cruise ships were more likely to detract from trip enjoyment than other motorized water craft. However, further analyses found that experiences with each form of mechanized transport can affect visitors' perceptions of experiences with other forms of transport.

Effect of different seasonal use conditions

An increase in seasonal use days from the current level of 153 to the maximum allowed of 184 was estimated to produce relatively few changes across all user groups, and these changes were primarily on measures of exposure to cruise ships. The largest predicted change in average hours visitors saw or heard cruise ships during their trip was 1.4 hours (from 4.3 to 5.7) for private vessel passengers.

For an aggregated measure of detraction from trip experience, the number of cruise ships in the bay was not predictive of likelihood of cruise ships to detract. However, for three user groups, the average hours visitors saw or heard cruise ships was predictive of increased likelihood of detraction from trip experience. Two of these user groups were also predicted to have an increase in average hours visitors saw or heard cruise ships if 184 seasonal use days are allowed. Thus, the higher average for hours visitors saw or heard cruise ships under 184 seasonal use days was used to predict likelihood that cruise ships would detract from visitor experiences. Based on these calculations, for 184 seasonal use days it is predicted that cruise ships will detract from the trip experiences for 68.3% of day boat passengers (up from 64.8%), and from 56.4% of all private vessel passengers (up from 50.6%). Across these and other analyses, the predicted changes due to increased seasonal use conditions were relatively small in magnitude.

Discussion and Management Implications

Many visitors of Glacier Bay proper are likely to see or hear a cruise ship for at least a short amount of time during their stay. Visitors were more likely to report that encounters with cruise ships detracted from specific trip experience dimensions or from their enjoyment of Margerie and Grand Pacific glaciers than from their overall enjoyment of Glacier Bay proper. Taken together, the findings suggested that the effects of seeing or hearing cruise ships were not sufficient to alter visitors' overall judgments of enjoyment for Glacier Bay proper. Be that as it may, park managers need to decide what opportunities they should provide for visitors and whether cruise ships are affecting important components of those opportunities. For example, if providing opportunities for solitude to particular user groups is important to park managers, then the findings showing that cruise ships detracted from solitude for each group must be weighed to determine if sufficient opportunities for solitude are available.

Experiences with one form of transport (e.g., cruise ships, tour boats, or aircraft) affected both the perceived effects of that form and of other forms as well. Apparently, experiences with mechanized transport get lumped together in visitors' minds, and visitors may be unable to separate and report the effects of each form. Thus, changes in visitors' reported perceptions of the effects of cruise ships may be due to experiences with other types of craft, and conversely, visitors' experiences with cruise ships may affect their perceptions of the effects of other forms of mechanized transport. Johnson (1990) also found that GLBA visitors' encounters with different forms of mechanized transport affected perceptions of their experiences with cruise ships. Recognizing the complexity of the relationship between experiences with mechanized transport and visitor experiences is important for park managers when considering changes to any form of mechanized transport in Glacier Bay proper.

Increasing seasonal cruise ship use days from 153 to 184 (maximum-allowed under EIS) is estimated to produce few changes of relatively small magnitude across user groups. Thus, if park managers feel that findings describing current conditions are consistent with the opportunities they wish to provide (between 37% and 67% of visitors in five of the user groups indicated that cruise ships detracted from their trip enjoyment), it is unlikely that increasing seasonal use days to 184 will substantially alter those desired opportunities.

University of Washington photograph by Mark Vande Kamp

Figure 3. Cruise ship sitting in front of Grand Pacific glacier on a typical weather day.

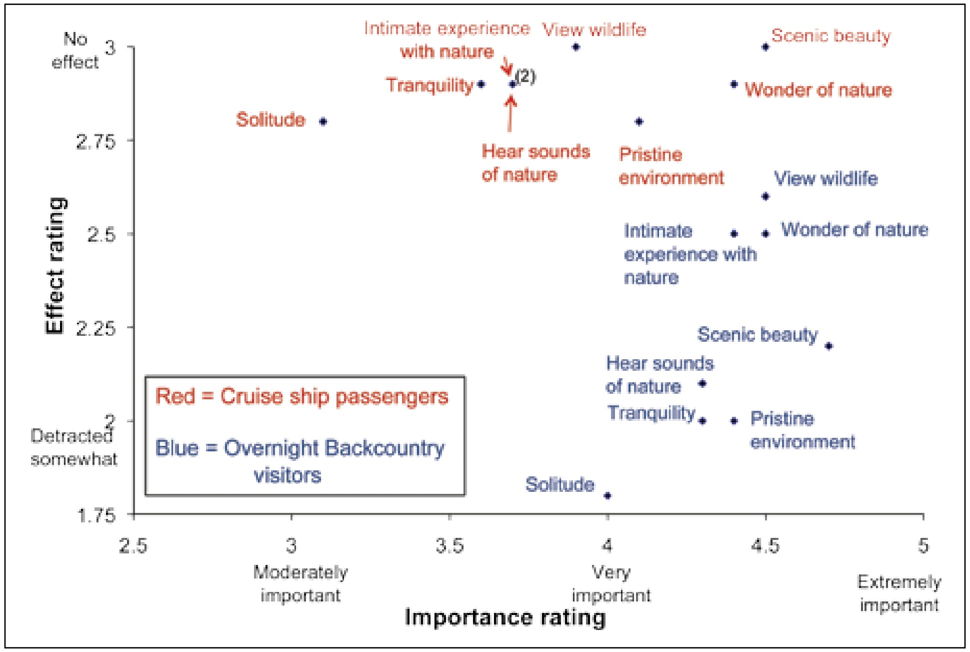


Figure 4. Effect of cruise ships on trip dimensions by importance of trip dimensions for cruise ship passengers and overnight backcountry visitors.

Acknowledgements

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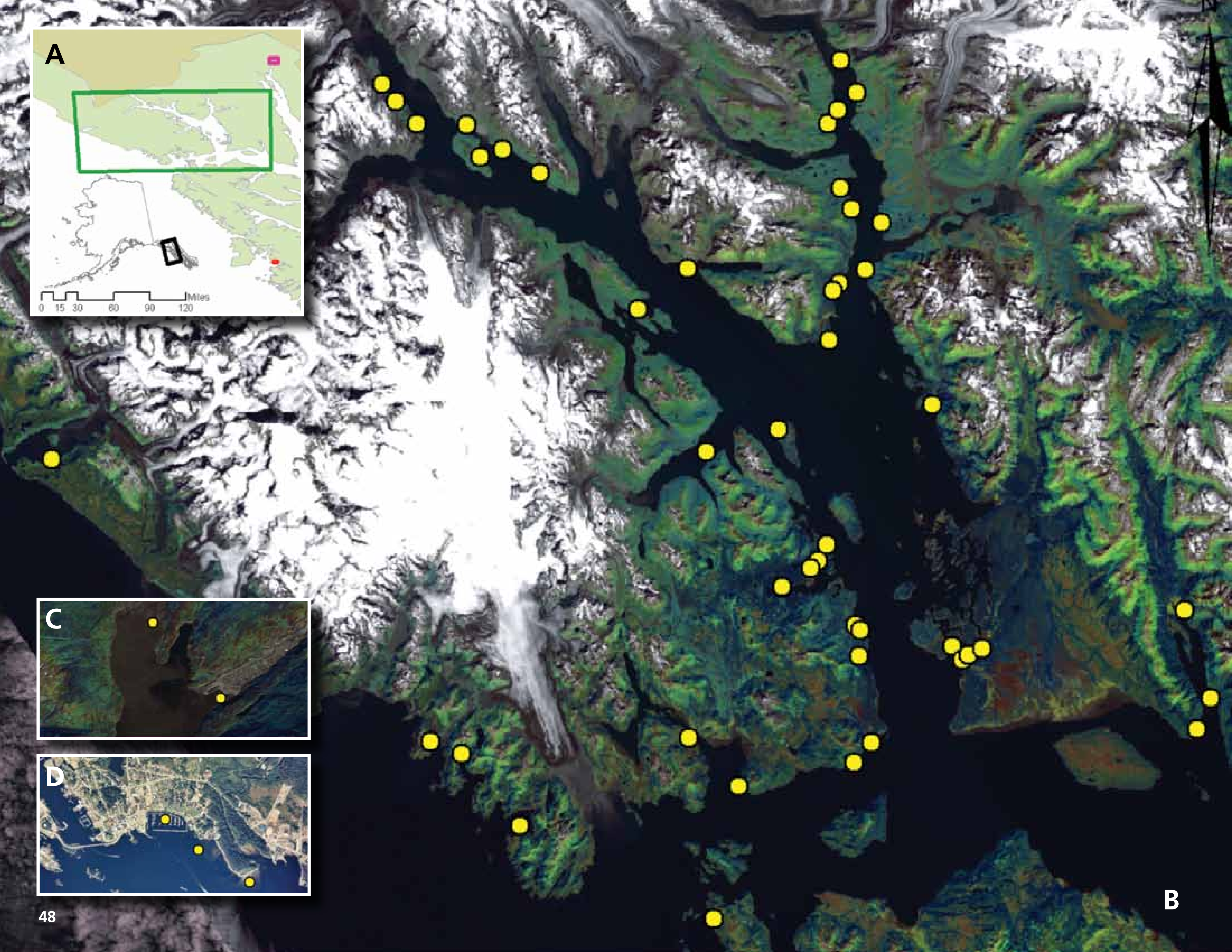
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A Marine Contaminants Assessment Suggests a Clean Intertidal Zone in Southeast Alaska Parks

By David A. Tallmon

Seemingly pristine and protected parks and natural areas can be negatively impacted by contaminants from distant, as well as nearby, sources. Contaminants can take many forms and threaten a variety of ecosystems and species. In the last few decades, research has shown that some contaminants can reach high latitudes from distant sources via different transport mechanisms and can accumulate in food chains, threatening the health of top predators and humans (*MacDonald et al. 2003, AMAP 2004*). There is increasing evidence from a broad array of studies that pollution created at relatively warm, low latitude sources can be transported to colder, higher latitudes via the "grasshopper effect" (*AMAP 2004*). Consequently, locales in northern regions can have surprisingly high levels of contaminants that are not broadly used or created nearby (*Engstrom and Swain 1997*). Recent research has shown that contaminants from a wide range of sources are a serious concern, even though the Gulf of Alaska is among the most pristine marine ecosystems yet tested for contaminants (*Hurwich and Chary 2000, Wright et al. 2000, Gabrielsen et al. 2003*).

Figure 1. Locations of mussels sampled for contaminants analysis. (A) Map of the SEAN region with GLBA outlined in green, KLGO outlined in pink, and SITK in red. The yellow dots on the other maps indicate sampling sites within and near each park: (B) GLBA, (C) KLGO, and (D) SITK.

NPS photograph

To assess current contaminant levels in Southeast Alaska parks (SEAN) and to determine whether these levels are high enough to be of concern, we examined three categories of contaminants in bay mussels collected at numerous sites (*Figure 1*). Mussels are useful study organisms because they are sessile filter feeders and live up to 20 years, providing insight into contamination that has occurred over the previous several years, while also serving as indicators of any recent catastrophic events. In addition, mussels are regularly collected for marine contaminant monitoring throughout the U.S. (*Kimbrough et al. 2008*). This provides us with the opportunity to compare our results to a massive, long-term database for mussels collected along the entire Pacific and Atlantic seaboards of the U.S.

Over 50 mussel samples were collected from Glacier Bay National Park (GLBA), Sitka National Historical Park (SITK), and Klondike Gold Rush National Historical Park (KGLO). These were analyzed for contaminant levels in three major categories: metals, polyaromatic hydrocarbons (PAHs), and persistent organic pollutants (POPs).

Metal contamination levels are low throughout SEAN intertidal zones. For example, arsenic and cadmium reach concentrations of 1 part per million (ppm) in mussels from only a few locations, and are very low values relative to the lower 48 states. Similarly, mercury levels are low throughout SEAN (< 0.03 ppm). Interestingly, the highest levels of mercury and tributyltin in this study are from a mussel sample collected in Crescent Harbor, Sitka, which has heavy boat use. Overall, the values for these metals are low relative to those found in both Alaska and the rest of the U.S. (*Kimbrough et al. 2008*). This suggests that SEAN, and southeastern Alaska in general, are relatively unaffected by metal contaminants in the intertidal zone.

Similarly, results show low levels of PAH and POP contamination in SEAN parks. Only a total of 11 samples included in this study are above the lower detection limit for PAHs, and these are almost all from heavy human use sites that were selected with an expectation of observing relatively high contamination levels. Results from this and other studies of a variety of plants and fishes inhabiting this and other parts of the U.S. generally suggest PAH contamination in SEAN is low (*Landers et al. 2008, Olsen et al. 2008*).

The region also shows low levels of contamination in the major POP groups analyzed. All but one site sampled

Figure 2. Mussels are common throughout the intertidal zone and were sampled for this study to examine marine contaminants.

have chlordane levels too low to be detected. Similarly, only seven sites have detectable DDT levels, and all of these are far below 5 parts per billion (ppb). All of these sites are heavy human use areas in or near KLGO, SITK, and GLBA. Only two sites have hexachlorocyclohexane levels that are above detection limits. Again, however, these values are very low (< 1 ppb), and provide little evidence this contaminant is a problem in the intertidal zone of SEAN. Although PCB levels are above detection limits in many samples, they are still extremely low in all but a few samples. In keeping with the PAH analyses, the sites with relatively high PCB and PBDE levels for the SEAN region have heavy human use, and would be categorized as low when compared to the most recent data taken across the U.S. (*Kimbrough et al. 2008*).

Although there are some sites with heavy human use that show evidence of contamination in southeastern Alaska, the analyses provide a clean bill of health for the intertidal zone of SEAN. In addition, the patterns suggest that at this point in time, there is no large, distant source of contaminants affecting SEAN at a level we can detect in the intertidal zone. Hopefully, this pattern will hold over time, and SEAN will remain the set of relatively pristine, uncontaminated jewels of Alaska that they are today.

Acknowledgements

This work was made possible by the contributions of many National Park Service employees, including: Scott Gende, Brendan Moynahan, Lewis Sharman, Chad Soiseth, Bill Johnson, Justin Smith, Deb Johnson, and Geof Smith. Kathy Smikrud and Peter Flynn provided the GIS maps presented here and helped with sample site identification. Micaela Ponce, Andrew Whiteley, and Erik Lokensgaard assisted with field collections.

NPS photograph

Figure 3. Mussels are an abundant component of the intertidal ecological community.

Photograph courtesy of David Tallmon

Figure 4. Micaela Ponce and Erik Lokensgaard collect mussles in the west arm of GLBA.

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Contrasting Trends of Harbor Seals and Steller Sea Lions in and near Glacier Bay National Park and Preserve

By Jamie N. Womble and Scott M. Gende

Understanding the potential impacts of cruise ships or other vessels to marine resources in Glacier Bay requires not just a measure of the degree of their interactions but also the status and trends of those resources. Two marine mammal species of particular interest to park managers are harbor seals (*Phoca vitulina richardii*) and Steller sea lions (*Eumetopias jubatus*) (*Figure 1*) due to their conservation status and potential to disturbance by vessels. Both species are apex-level predators and are highly sought after viewing experiences for visitors. Steller sea lions, which are currently listed under the Endangered Species Act (ESA), have a prominent haul out site at South Marble Island (*Figure 2*) where private and tour vessels regularly visit. Harbor seals have been designated as a "species of special concern" in Alaska by the U.S. Marine Mammal Commission, and vessels regularly visit Johns Hopkins Inlet in the West Arm of Glacier Bay where approximately two-thirds of the seals in the park are found on icebergs calved from tidewater glaciers (*Mathews and Pendleton 2006, Womble et al. 2010*).

Given the conservation concerns associated with both of these highly visible marine mammal species, population monitoring efforts by various agencies and academic institutions were initiated a number of years ago and have since spanned several decades in the Glacier Bay region. In fact, Glacier Bay is one of only two glacial ice sites in Alaska where long-term monitoring efforts for harbor seals have occurred since the 1970s (*Streveler 1979, Calambokidis et al. 1987, Mathews and Pendleton 2006, Womble et al. 2010*).

The results of these monitoring efforts demonstrate surprisingly contrasting trends for the two species. For harbor seals, dramatic declines have occurred in Glacier Bay over the 17-year period from 1992-2008 at both glacial ice and terrestrial haul outs (*Mathews and Pendleton 2006, Womble et al. 2010*). The steepest declines (-11.5%/year) occurred at terrestrial sites from 1992-2001 and 2004-2009. At the primary glacial ice site in Johns Hopkins Inlet, pup counts had a significant negative trend of -5.0%/year for the 15-year period from 1994 to 2008, while the number of non-pups counted in August declined at -8.2%/year from 1992 to 2008 (*Mathews and Pendleton 2006,Womble et al. 2010*). In contrast, Steller sea lions in the Glacier Bay region have increased at a rate of 8.2%/year from the 1970s to 2009, with the most rapid growth at South Marble Island (16.6%/year from 1991-2009) (*Mathews et al. in press*). The growth in the number of Steller sea lions counted in the Glacier Bay region represents the most rapid growth for the species in Alaska (*Mathews et al. in press*) and is concurrent with the overall growth of the eastern population segment of Steller sea lions, which has increased at a rate of 3.1%/year from the 1970s to 2004 (*Pitcher et al. 2007*).

The decline of harbor seals in Glacier Bay is surprising given that the park is one of the largest northern temperate marine reserves (949 mi^2/2,457 km^2) in existence. During the breeding season, regulations are in place to protect harbor seals including closures of important seal pupping areas to vessel traffic and restrictions on approach distances by vessels. Though, compliance by cruise ship and other vessel operators in Johns Hopkins Inlet to these approach-distance regulations was found to be low (*Young 2009*). There also exists a prohibition of subsistence hunting for seals since 1974 (*Catton 1995*), and commercial fishing in Glacier Bay proper is being phased out. The decline in the number of harbor seals counted in Glacier Bay is particularly perplexing given that population trajectories in other regions (Ketchikan and Sitka) in southeastern Alaska have been increasing or stable (*Small et al. 2003*).

In response to declines in harbor seals, research was initiated by the NPS in 2004 to address hypotheses related to the decline including assessing human disturbance at harbor seal haulouts as a result of vessel traffic, determining health and disease status, and identifying habitat use and movement patterns of seals during the overwinter-period when disturbance and vessel protections are not in place.

Several lines of evidence suggest that the Glacier Bay region may be particularly favorable for Steller sea lions. First, sea lions have colonized several new haulouts and a rookery at Grave Rocks (*Pitcher et al. 2007, Womble et al.*

Figure 1. (A) Steller sea lions ashore at a rookery near the park. (B) Steller sea lion rookery at Graves Rocks. (C) Harbor seals resting on iceberg that was calved from McBride Glacier in McBride Inlet.

(A and B) Photograph courtesy of Kevin S. White, Alaska Department of Fish and Game
(C) NPS photograph by Jamie N. Womble

NPS photograph by Jamie N. Womble

Figure 2. Steller sea lion haulout site at South Marble Island.

Photograph courtesy of Bill Eichenlaub

Figure 3. Steller sea lions aggregated near spring-spawning fish run in Adams Inlet in the East Arm of Glacier Bay.

2009, Mathews et al. 2010). Second, South Marble Island, the primary Steller sea lion haulout site, was colonized by sea lions as recently as 1985 and was used only seasonally through the 1990s. However, South Marble Island is currently occupied throughout the year by sea lions with breeding season counts exceeding 1,100 sea lions (*Womble et al. 2009, Mathews et al. in press*). Third, foraging opportunities are likely favorable for sea lions in Glacier Bay as it relates to the availability of spring-spawning fish aggregations (*Figure 3*) (*Womble et al. 2005*) and the colonization of salmon of Glacier Bay (*Milner and Bailey 1989*). Both of these prey resources likely provide high-energy densely aggregated prey for sea lions at critical times of year (*Womble et al. 2009*). Finally, the increase in the number of sea lions counted in the Glacier Bay region is of particular interest as it relates to the decline of sea lions in the western population (*Mathews et al. in press*). Recent genetic evidence suggests that Steller sea lions from both the eastern and western populations colonized the Graves Rocks sea lion rookery in the Glacier Bay region (*Gelatt et al. 2007, O'Corry-Crowe et al. 2007*).

It is currently unknown if there is a relationship between the population trajectories of these two pinniped species. Steller sea lions and harbor seals use similar foraging habitat and consume similar prey species including walleye pollock, capelin, Pacific sandlance, herring, and salmon in the Glacier Bay area (*Gelatt et al. 2007, Herreman et al. 2009*). Such foraging overlap could result in negative population-level effects on harbor seals if prey become limiting, and sea lions are able to out-compete seals for these resources. Dramatic changes in the landscape due to rapid glacial retreat may also influence harbor seals and Steller sea lions differently given their life-history strategies. For example, between 1973 and 1986, the Muir Glacier, a tidewater glacier in the East Arm of Glacier Bay, retreated more than 4.3 miles (7 km). The dramatic retreat and subsequent grounding of the Muir Glacier resulted in the cessation of calving of the Muir Glacier in 1993 (*Hall et al. 1995*). As a result, the availability of floating glacial ice as a haulout substrate for harbor seals in Muir Inlet was reduced and eventually resulted in the abandonment of upper Muir Inlet by harbor seals. Prior to the grounding of Muir Glacier, at least 1,347 seals were counted in upper Muir Inlet in the East Arm of Glacier Bay in the 1970s (*Streveler 1979*); however, in 2008 fewer than 200 seals were counted in McBride Inlet near the terminus of the McBride Glacier, which is the only remaining tidewater glacier in the East Arm of Glacier Bay (*Womble et al. 2010*).

In 1879 John Muir visited Glacier Bay and wrote of "the whiskered faces of seals that dotted the open spaces between the bergs" (*Muir 1915*). Clearly changes in the population dynamics of seals and sea lions are occurring in Glacier Bay. Understanding long-term population trajectories for harbor seals and Steller sea lions is important as we might expect each species to respond to natural and anthropogenic change differently given their unique life-history characteristics. Ultimately, long-term population monitoring programs are critical component of park management as they provide estimates of population trends of species of conservation concern and can be used to inform decisions regarding management actions that may have potential to adversely impact these species.

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Disturbance of Harbor Seals by Vessels in Johns Hopkins Inlet

By Colleen Young, Scott M. Gende, and James T. Harvey

Introduction

Harbor seals (*Phoca vitulina richardii*) are one of the most abundant marine mammal species found across the Pacific Rim, ranging from Baja California to the Bering Sea. Although they spend much of their time in the water, foraging in diverse aquatic habitats including small lakes, large rivers, and open ocean, harbor seals, like other species of seals and sea lions, need to frequently exit the water ('haul out') to rest, give birth, and nurse pups. Seals haul out on land or ice, and may occur in large aggregations, particularly in glacial fjords. For example, in Icy Bay, Alaska, over 5,000 harbor seals may haul out at certain times of the year.

Harbor seal haulouts are popular destinations for private vessel operators, eco-tours, and cruise ships (*Figure 1*), but visitation by vessels can result in disturbance of seals. Disturbances can be subtle and somewhat benign, such as a seal lifting its head to look at an approaching vessel, or more severe, such as when vessels cause seals to flush from their haul-outs (land or ice) and enter the water. Flushing is problematic because it is energetically costly, particularly during molting, when seals shed and replace their fur coat, and may impact reproductive success by separating mother-pup pairs, or interrupting nursing.

In Glacier Bay National Park and Preserve (GLBA), certain areas of the park are subject to vessel regulations that are either generally or specifically mandated to protect seals from the deleterious impacts of disturbance. For example, in the lower section of the park, harbor seals regularly haul out on land at the Spider Island Reef Complex. Throughout the year, vessel operators are required to stay at least 0.25 nautical miles (463 m) from these islands in order to minimize the chance of disturbance to harbor seals. Likewise, Johns Hopkins Inlet, where up to two-thirds of seals in the park haul out on icebergs during the summer, has been designated "critical seal habitat." This designation affords seals extra protection from disturbance through specific management regulations (*Figure 2*).

Despite these regulations, there is concern about the impacts of vessels on ice-hauling seals in Johns Hopkins Inlet because it was historically home to one of the largest breeding aggregations of seals in Alaska (*Streveler 1979*) but the abundance of seals has decreased precipitously since 1992 (*see Womble et al. this issue)*. To date, a number of hypotheses have been proposed as to why seals have declined in Glacier Bay, including changes in prey base, increased levels of predation, and vessel disturbance. Vessel disturbance was important to evaluate because disturbance, unlike natural stressors, can be regulated by park management. Furthermore, several opportunistic reports suggested that compliance with regulations has been minimal.

Figure 1. A cruise ship approaches an ice berg upon which several seals are hauled out.

NPS photograph by Jamie Womble

Methods

The objectives of this study were to characterize and quantify the disturbance regime experienced by seals in Johns Hopkins Inlet. To do so, we established a field camp in the inlet for two to four weeks at a time during the summer field season (June-September) in 2007 and 2008, and recorded information about all vessels (cruise ships, tour vessels, private vessels, and kayaks) (*Figure 3*). We also assessed haulout behavior of harbor seals by recording behavior of seals (in the absence of vessels) as well as vessel-induced changes in behavior. We then used these data to evaluate the effectiveness of, and compliance with, existing management regulations.

Results

Over the course of the study we were in Johns Hopkins Inlet for a total of 64 days, and observed 178 vessels entering the inlet. Vessel use varied dramatically among days, months, and years. Vessels never entered the inlet in June, which demonstrated 100% compliance with the June vessel restriction regulation. Private and tour vessels entered Johns Hopkins Inlet the remaining summer months, whereas kayaks only entered during July and August, and cruise ships only were present in September (*Figure 4*).

Vessel behavior in Johns Hopkins Inlet differed among vessel types, and was largely influenced by ice conditions. For example, private and tour vessels tended to stay along the edges of ice floes, only approaching Johns Hopkins Glacier when ice was sparse or if there was an ice-free lead through the inlet. Cruise ships, on the other hand, frequently traveled to the head of the inlet, regardless of ice conditions. Kayaks, in contrast, generally avoided dense ice, and often turned around at the mouth of the inlet when ice cover was substantial.

The daily number of seals flushed by vessels ranged from 0 to 63 with an average of 15 per day attributed to vessels. Consequently, the flush rate (37%) in the presence of vessels was nearly double that compared to when vessels were absent (17%). However, not all vessel types were equally disruptive: 86% of cruise ships flushed at least one seal, followed by tour vessels, private vessels, and kayaks (*Figure 5*). Cruise ships caused the greatest magnitude of disturbance, flushing an average of 11.5 seals per vessel, followed by private vessels (7.5 seals), tour vessels (4 seals), and kayaks (3 seals).

As seals in the inlet typically hauled out in the areas of densest ice cover and because vessel behavior was

Regulation	Geographic Area	Timeframe
Vessel access restriction – all vessels	Johns Hopkins Inlet	1 May – 30 June
Vessel access restriction – cruise ships	Johns Hopkins Inlet	1 May – 31 August
0.25 nm minimum vessel approach distance to harbor seals	Johns Hopkins Inlet, Spider Island Reef Complex	1 July – 31 August
10-knot speed limit when operating around harbor seals	Johns Hopkins Inlet	1 July – 31 August
Daily vessel quotas – Cruise ships: 2 Tour vessels: 3 Private vessels: 25	Glacier Bay National Park	 1 May – 30 September 1 May - 30 September 1 June – 31 August

Photograph courtesy of Lindsay Carroll

Figure 2. (Left) Summary of harbor seal related vessel regulations in Glacier Bay National Park and Preserve.

Figure 3. (Right) An observer records harbor seal behavior in Johns Hopkins Inlet.

largely dependent on ice conditions, the propensity for vessel disturbance of seals was impacted by ice cover. In general, vessels that were further from seals were less likely to cause a disturbance. The cumulative frequency of flushing versus distance (*Figure 6*) illustrates the relationship between distance and the occurrence of flushing. Nevertheless, the response of harbor seals to approaching vessels was extremely variable with some animals flushing at great distances from vessels, while others seemingly ignored vessels completely. Our results indicated that, in addition to ice cover, vessel approach distance and vessel type were important variables to include when predicting the probability of flushing.

Whether, and to what degree, vessels were in compliance with seal disturbance laws and regulations depended upon whether the regulation specified separation distance with seals or modification of their behavior. For example, if we defined disturbance as whether or not a seal flushed from the ice in response to a vessel (independent of the approach distance of the vessel), then 72% of vessels observed during the study caused a disturbance. Only 12% of vessels that entered the inlet on study days fully complied with the 0.25 mile minimum approach distance regulation. Many vessels approached seals within 0.25 mile but did not flush any seals, and many seals flushed when vessels were at distances greater than 0.25 mile. Among 71 vessels that violated the distance regulation, 936 seals were approached closer than 0.25 mile. These vessels were responsible for 69% of all animals flushed during the study period.

Conclusions and Management Implications

As expected our study found some management-relevant results but also, as with many scientific studies, generated a number of new questions. The presence of all vessel types in the inlet was found to alter the haulout behavior of harbor seals. The great magnitude of cruise ship-induced disturbance was consistent with studies from other areas (*Jansen et al. 2010*). It is unknown whether cruise ships flush seals at a greater rate because they are larger and can be seen from a greater distance, or because they are more likely to proceed through ice conditions that otherwise prohibit smaller vessels. It is difficult to separate characteristics, such as ship size (would private vessels flush a similar number of seals if they were the same size as cruise ships?), from characteristics like vessel behavior (would cruise ships flush equal number of seals if they avoided dense ice, like private vessels?). Regardless, although responsible for flushing more seals per vessel, cruise ships are restricted to entry into Johns Hopkins Inlet during September, when seals are not burdened by the energetic demands of pupping and molting.

Overall compliance of vessels with park-specific and federal (Marine Mammal Protection Act) regulations was minimal. Kayaks were the most compliant, though this is probably a result of their reluctance to approach most seals due to ice conditions. Cruise ships, conversely, accounted for the greatest percentage of violations. The overall proportion of the seals that were disturbed by vessels was relatively low. This finding indicates that it is unlikely that disturbance of harbor seals by vessels alone was a driving factor in the historical demographic change, although increased vessel use of the inlet in recent years may be compounding other deleterious factors potentially affecting seals, such as decreased quantity and quality of prey, or disease. The potential energetic costs of flushing, the significance of glacial fjords as critical pupping habitat (thus potential source populations), and the legal obligation to uphold the Marine Mammal Protection Act all underscore the importance of minimizing anthropogenic impacts in Johns Hopkins Inlet.

Based on the findings from this study, we recommend that resource managers consider increasing enforcement of current regulations, potentially modify existing park regulations, and encourage boaters to

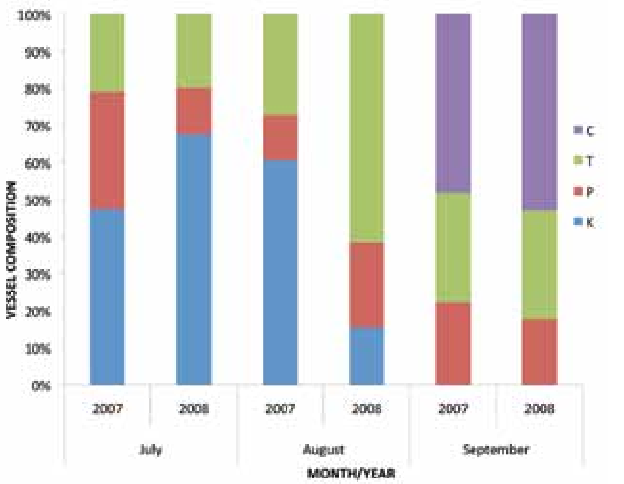

Figure 4. Monthly vessel traffic, by vessel type, in Johns Hopkins Inlet. Vessels were classified as cruise ships (C), tour vessels (T), private vessels (P), and kayaks (K).

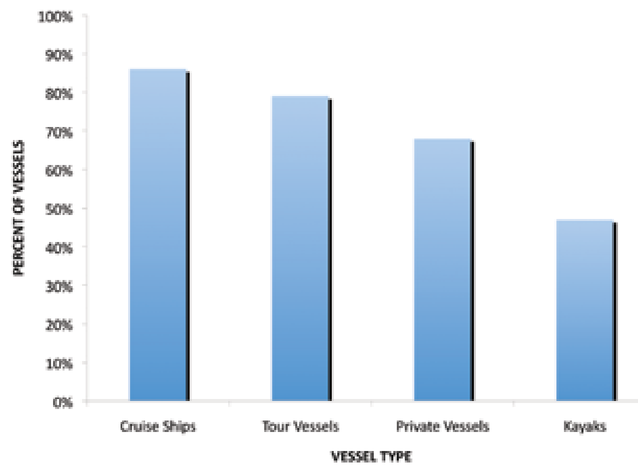

Figure 5. Disturbance rates of harbor seals among vessel types. Disturbance rate was calculated as the percent of each vessel type that entered Johns Hopkins Inlet and flushed at least one seal.

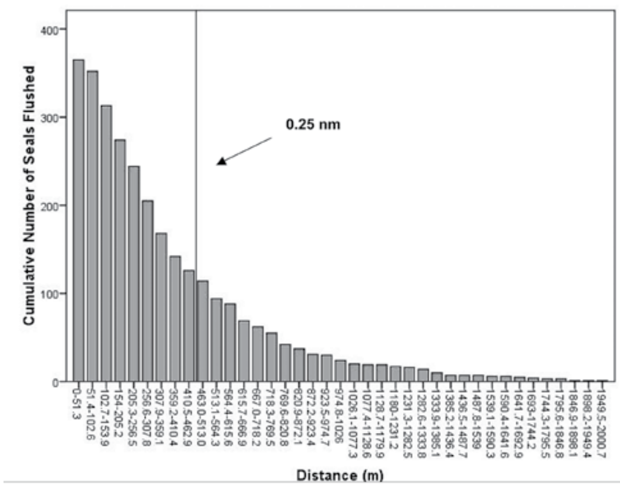

Figure 6. Cumulative frequency of seal flushing based on the distance of an approaching vessel.

Modification	Justification
• Survey JHI for un-weaned pups before opening JHI to vessel traffic.	• Prevent mother-pup separation for late-weaners.
• Enhance education of boaters regarding seal-related vessel regulations during backcountry orientation for private boaters, and through a training session or video for tour vessel and cruise ship captains.	• Voluntary compliance with existing regulations would probably greatly reduce disturbance of harbor seals in JHI.
• Increase enforcement of the 0.25 nm minimum distance requirement.	• Enforcement (or threat of enforcement) would likely increase compliance with this important regulation.
• Restrict cruise ship visitation of JHI to 5km into the inlet.	• The majority of seals haul out near the face of the glacier, so this would greatly reduce the number of potential disturbance events.
• Restrict all vessel visitation of JHI to morning and late afternoon hours.	• Since fewer seals haul out during these times, the potential for disturbance will be decreased.

Figure 7. Suggestions for possible modifications to current harbor seal-related vessel regulations.

comply with federal regulations (*Figure 7*). Adopting one, or a combination, of these modifications may substantially decrease the frequency and magnitude of disturbance of harbor seals by vessels in the inlet.

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NPS photograph by Jamie Womble